STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF MAINTENANCE
OFFICE OF EQUIPMENT

VEHICULAR IMPACT TESTS OF A TRUCK MOUNTED ATTENUATOR CONTAINING VERMICULITE CONCRETE CELLS

Study made for .... Office of Equipment

Study made by .... Transportation Laboratory

Under the Supervision of .... Eric F. Nordlin, P.E.
Jim Roberts, P.E.

Principal Investigator .... J. Robert Stoker, P.E.

Co-Principal Investigator .... Roger L. Stoughton, P.E.

Report prepared by .... Roger L. Stoughton, P.E.

Consultants .... John Marlow, P.E.
Rick Campbell
Calvin Schiefferly

APPROVED BY

Neal Andersen

NEAL ANDERSEN, Chief
Transportation Laboratory

J T Kassel

J. T. KASSEL, Chief
Office of Equipment

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16. ABSTRACT

Six vehicular impact tests were conducted. Cars ranging in weight from 1890 lbs to 4480 lbs impacted the rear end of dump trucks at speeds of 45 mph. In five of the tests truck mounted attenuators (TMA's) were used on the trucks. The TMA tested was a 6 ft-0 in. long by 8 ft-0 in. wide by 2 ft-0 in. high plywood box enclosing 84 crushable vermiculite concrete cells arranged in a designed pattern.

The tests were intended to study 1) the effectiveness of the TMA in reducing car and truck damage and decelerations, 2) the vehicle trajectories after impact and specifically the roll ahead distance of the trucks using different truck braking conditions, and 3) other characteristics of the TMA's such as ease of use, amount of debris after impacts, durability, etc.

It was concluded that the TMA was quite helpful in reducing vehicle damage and decelerations for light to moderate impact conditions. At impact speeds of 45 mph, almost full benefit of the TMA's was gained by 4500 ± lb cars, but the crash environment was severe for lightweight cars at that speed with decelerations over 12 g's. Truck roll ahead distances were under 14 feet for all tests. It was recommended that the TMA's be installed on dump trucks susceptible to rear end impacts. The State has purchased 80 of the type of TMA that was tested.

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NOTICE

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quanity	English unit	Multiply by	To get metric equivalent
Length	inches (in)or(")	25.40 .02540	millimetres (mm) metres (m)
	feet (ft)or(')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2) square feet (ft^2) acres	6.432×10^{-4} .09290 .4047	square metres (m^2) square metres (m^2) hectares (ha)
Volume	gallons (gal) cubic feet (ft^3) cubic yards (yd^3)	3.785 .02832 .7646	litres (l) cubic metres (m^3) cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour(mph) feet per second(fps)	.4470 .3048	metres per second (m/s) metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity(G)	9.807	metres per second squared (m/s^2)
Weight Density	pounds per cubic (lb/ft^3)	16.02	kilograms per cubic metre (kg/m^2)
Force	pounds (lbs) kips (1000 lbs)	4.448 4448	newtons(N) newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds(ft-lb) foot-kips (ft-k)	1.356 1356	joules (J) joules (J)
Bending Moment or Torque	inch-pounds(ft-lbs) foot-pounds(ft-lbs)	.1130 1.356	newton-metres (Nm) newton-metres (Nm)
Pressure	pounds per square inch (psi) pounds per square foot (psf)	6895 47.88	pascals (Pa) pascals (Pa)
Stress Intensity	kips per square inch square root inch (ksi $\sqrt{in}$)	1.0988	mega pascals $\sqrt{metre}$ (MPa $\sqrt{m}$)
	pounds per square inch square root inch (psi $\sqrt{in}$)	1.0988	kilo pascals $\sqrt{metre}$ (KPa $\sqrt{m}$)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (F)	$\frac{tF - 32}{1.8} = tC$	degrees celsius (°C)

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Office of Equipment

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Energy Absorption Systems Inc.

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1. INTRODUCTION

1.1 Problem

Slow moving or parked trucks used to shadow or shield maintenance activities on a high speed highway pose a special safety problem. Even though signs, flashing lights, and traffic cones are carefully placed to warn the public, inattentive motorists occasionally still crash into the backs of the trucks. This problem has increased and accidents have resulted in the deaths of Caltrans maintenance workers.

Caltrans is taking a number of corrective steps to mitigate this traffic problem. One measure taken was to order truck mounted attenuators (TMA's) for all vulnerable trucks in 1979. A TMA is a compact crash cushion which is suspended from the back of the truck. It is similar in concept to those placed in front of fixed objects at freeway offramps. The purpose of the TMA is to reduce damage to both the impacting vehicle and the maintenance truck and, particularly, to lessen the severity of injuries to passengers of either vehicle.

After studying the four types of TMA in 1979 which are currently in use in the United States, the Caltrans Office of Maintenance selected one manufactured by Energy Absorption Systems, Inc. (EAS). This type absorbs energy from cars by the crushing of many vermiculite concrete cylinders which are placed in specific patterns inside the TMA. Although there was some crash test and field experience on this design, it was decided that additional crash tests were needed to learn its full capabilities.

1.2 Objectives

The Caltrans Office of Equipment was responsible for outfitting trucks with the new TMA's. They instigated this research, which consisted mainly of six vehicle crash tests, with the following objectives in mind:

- To measure the difference in roll ahead distance between a truck with a TMA having all wheels braked and one having only the rear wheels braked when struck by 4500 lb cars.
- To measure the difference in roll ahead distance between trucks with TMA's that are struck by a 4500 lb car, a 2250 lb car, and a 1900 lb car.
- To determine the amount of vehicle damage and the vehicle decelerations for the above tests as a measure of TMA effectiveness.
- To compare the above tests with one in which a 4500 lb car strikes the truck and TMA at an angle of 15° and with the car and truck centerlines offset 3 ft-0 in. from each other.
- To compare all the tests with one in which a 4500 lb car strikes a truck without a TMA.
- To determine the optimum size and weight of truck to be used with a TMA.

The roll ahead distances are needed to set standards for the distances maintenance men or slow moving maintenance equipment can work safely in front of parked or slow moving maintenance shadow trucks. Vehicle decelerations are a gauge of vehicle passenger safety. Since few crash tests have been conducted on TMA's of any type, this series of tests also will serve as a basis for comparison with tests on future TMA designs.

This project marks the first time Caltrans has conducted a crash test with a car weighing less than 1940 lbs. Recently, FHWA has encouraged tests with 1700-1800 lb cars due to their rapid growth in the car population. All tests were conducted in accordance with Transportation Research Circular No. 191 (1)* where possible.

1.3 Background

A brief description of the four known existing types of TMA follows.

The first TMA was developed and tested at the Texas Transportation Institute (TTI) in 1972. It consists of an array of empty 55 gallon steel drums, like those used in highway crash cushions. The drums are mounted on a simple one axle trailer. The TMA is rigidly attached to the back of the truck and extends about 20 ft behind it. It has been tested successfully by a car impacting it at 60 mph (2). A variation of the Texas design was first used in Ontario, Canada in 1975 (3). It performed well in two accidents. The long length of these TMA trailers makes them cumbersome to tow. There was further concern that the rigid TMA to truck connection could result in weld fatigue and excessive tire wear.

*Numbers in parenthesis refer to a reference list at the end of this report.

Transpo-Safety, Inc. of New Rochelle, New York manufactures a TMA called Cushion Safe. It consists of a cluster of water-filled, tubular vinyl cells which expell water through small holes in the top of the cells, and thus absorb energy, during impacts. This unit has serious disadvantages due to its heavy weight and shallow collapse depth. The entire unit hangs from and projects only about 28 inches beyond the back of the truck. Except for impacts at low speeds, decelerations would be too high for the safety of passengers. No rigorous crash testing has been performed on this unit.

The University of Connecticut developed a TMA using a row of vertical steel pipe sections mounted on a sliding frame support. Four two-foot diameter by 34-inch high sections of pipe with wall thicknesses of 1/4 inch and 3/8 inch are used. Impacting vehicles strike an aluminum plate assembly at the back of the TMA which travels forward, successively crushing the four pipe sections. Maximum possible collapse distance for the TMA is about 8 ft-0 in.; the TMA is hung from and projects back a total of 9 ft-3 in. from the rear of the truck. In a series of four crash tests in the fall of 1976 at Calspan this design performed effectively (4,5). Results of the tests are included in tables in this report for comparison. This design was also rejected by Caltrans because of excessive weight and minimal ground clearance. A heavy TMA reduces the payload that a truck can carry while also serving as a protective "barrier". (Subsequently the University of Connecticut reduced the weight of the aluminum impacting plate assembly from 430 to 278 lbs. Two crash tests were conducted by TTI in 1978 (6). The

Caltrans researchers learned of the report too late to include results in summary tables. There was improvement in peak acceleration values for a lightweight car test, but no improvement in 50 ms. average values of acceleration.)

Energy Absorption Systems, Inc. (EAS) located in West Sacramento developed the TMA which was selected for testing and use by Caltrans. This unit was subjected to six crash tests by the manufacturer in late 1974 and early 1975. For that series of tests, the Caltrans Office of Equipment supplied a dump truck on which to mount the TMA. The Transportation Laboratory observed some of the tests and took movies and photos of the final test (7). Only headon tests (no angle) with heavy cars were conducted. It was concluded at that time that the TMA design was sufficiently refined for limited use on a trial basis. It was also recommended that tests be conducted with a small car impacting headon, and a large car impacting offset from the truck centerline at a later time. Caltrans did purchase a few units for trial use, but there was a lack of funds available to buy many units or to continue the research at that time.

Since that time accidents involving Caltrans maintenance vehicles have been frequent. In 1978 there were 64 accidents, 43 of which were rear end collisons. In most cases the Caltrans vehicle was a truck or pickup. The accidents have included Caltrans vehicles that were moving, were parked and occupied, and were parked with Caltrans workers in front of their vehicles. A summary of those accidents is included in Appendix E.

Near the time this report was completed, Caltrans researchers learned that Fibco, Inc. has done developmental work and two crash tests at Calspan on a fifth type of TMA which uses expanded surlyn sheet material in a quasi-honeycomb structure as the energy absorbing material (8). Fibco concluded their final design was acceptable.

2. CONCLUSIONS

The following conclusions were based on the results of six 45 mph passenger car impact tests into the back ends of dump trucks weighing about 11,700 lbs., five of which were shielded with truck mounted attenuators (TMA). The test results were judged in comparison with the appraisal standards in Transportation Research Circular No. 191 (1), and with the results of five other similar tests conducted by other agencies. The three appraisal factors used to judge results were structural integrity, impact severity, and vehicle trajectory.

2.1 Structural Integrity

1. Although damage to the impacting passenger car front ends was severe in all TMA tests, there was virtually no collapse or intrusion of the passenger compartment by vehicle or TMA components. In the control test with no TMA the front end crush of the car was much more severe and there was slight intrusion of the car passenger compartment which would have increased at speeds over 45 mph.

2. There was slight damage to the rear end of the truck in only one test where the TMA was employed, whereas the truck in the control test with no TMA incurred moderate damage.

3. Most or all of the vermiculite concrete cells inside the TMA were effectively crushed in all tests. Debris from the crushed cells and plywood enclosure was minimal and stayed close to the area of impact.

4. It is doubtful whether the more flexible steel grid support under the TMA, used for all tests after Test 374, was helpful in reducing car accelerations.

5. There was practically no damage to the steel backup frame and mounting controls on the TMA in all tests.

6. In all tests the car had small values of pitch, roll, and yaw; hence, the pentration of the car into the TMA was controlled, and there was no instability of the car or truck.

2.2 Impact Severity

1. The impacting passenger car accelerations in the control test with no TMA were unacceptably high: -21.5 g's compared with a preferred maximum of -6 to -8 g's and a permissible maximum of -12 g's.

2. The TMA lowered the car accelerations in the 4500 lb car tests to acceptable values under -12 g's, but the impact speeds of 45 mph could not have been raised much without exceeding the -12 g limit.

3. Accelerations for an 1890 lb and 2140 lb car were less than the control test value, but were over the -12 g limit. This indicates that unless the TMA design is revised, it can only meet acceleration standards at impact speeds <u>less</u> than 45 mph for lightweight and mini-weight cars.

4. When the TMA was struck offset and at an angle by a 4500 lb car at 45 mph, the car accelerations remained tolerable.

5. Theoretical values of dummy head relative velocity when striking the car windshield after two feet of travel were relatively high. They indicate that the TMA would be most beneficial if car passengers were wearing lap belts and shoulder belts.

6. Truck accelerations were relatively low, in the 2-4 g range, for the TMA tests. These values are not excessive except for their potential in causing whiplash or other head injuries to truck drivers and passengers, if well designed head restraints are not used in truck cabs.

2.3 Vehicle Trajectory

1. The trucks, which were all in second gear and had some or all wheels braked, traveled relatively short distances (2.4 to 13.8 ft) ahead after impact by the passenger cars at 45 mph. The cars followed closely behind. This would cause minimal effect on adjacent traffic.

2. The roll ahead distances for the trucks were relatively small for 45 mph impacts by cars. Calculations

of roll ahead distances for other conditions, however, show it would be impractical to rely completely on the trucks for protection of work crews, considering higher speed impacts and impacts by trucks and buses.

3. The truck roll ahead distances were less when all wheels were braked as opposed to having only the rear wheels braked.

4. Truck roll ahead distances are not affected significantly by the use of TMA's.

2.4 General

1. The EAS TMA performance was similar to that of the TMA developed at the University of Connecticut.

2. Considering all the above factors, the TMA is an effective energy absorbing device for a limited but useful range of impact conditions. These conditions include 4500 lb. passenger cars impacting dumptrucks with TMA's (gross weight 13,000 lbs. maximum), parked in gear and braked, at speeds of 45 mph or less, and 2250 lb. (lightweight) cars and 1900 lb. (miniweight) cars impacting at speeds somewhat less than 45 mph. The impact speed could be higher for all size cars if the truck were a) not in gear and not braked b) moving or c) lighter weight; however, these changes would all increase the truck roll ahead distance. Any other improvements in impact severity would necessitate lengthening the TMA and softening some of the energy absorbing cartridges. It is difficult to calculate limiting values for these changed conditions.

3. RECOMMENDATIONS

1. The TMA should be installed on slow moving or parked Caltrans trucks and heavy maintenance vehicles that are susceptible to rear end impacts.

2. Users of the TMA and their supervisors should be carefully informed about the capabilities and the limitations of the TMA.

3. The new research study to develop a lightweight TMA by the Office of Equipment which is just getting underway should focus on improved performance for lightweight and miniweight cars impacting the TMA.

4. The Office of Equipment should continue with their plans to develop and test a head restraint for use in truck cabs.

5. The operational and impact performance of the TMA's in use should be monitored for a period of at least three years.

6. Dump trucks mounted with TMA's should carry little, if any, payload because added truck weight will tend to increase impacting car deceleration levels.

4. IMPLEMENTATION

The Office of Equipment has purchased 80 TMA's and will be installing them on trucks in 1980. The Office of Maintenance will be the principal user of the TMA's.

5. TECHNICAL DISCUSSION

5.1 Test Conditions

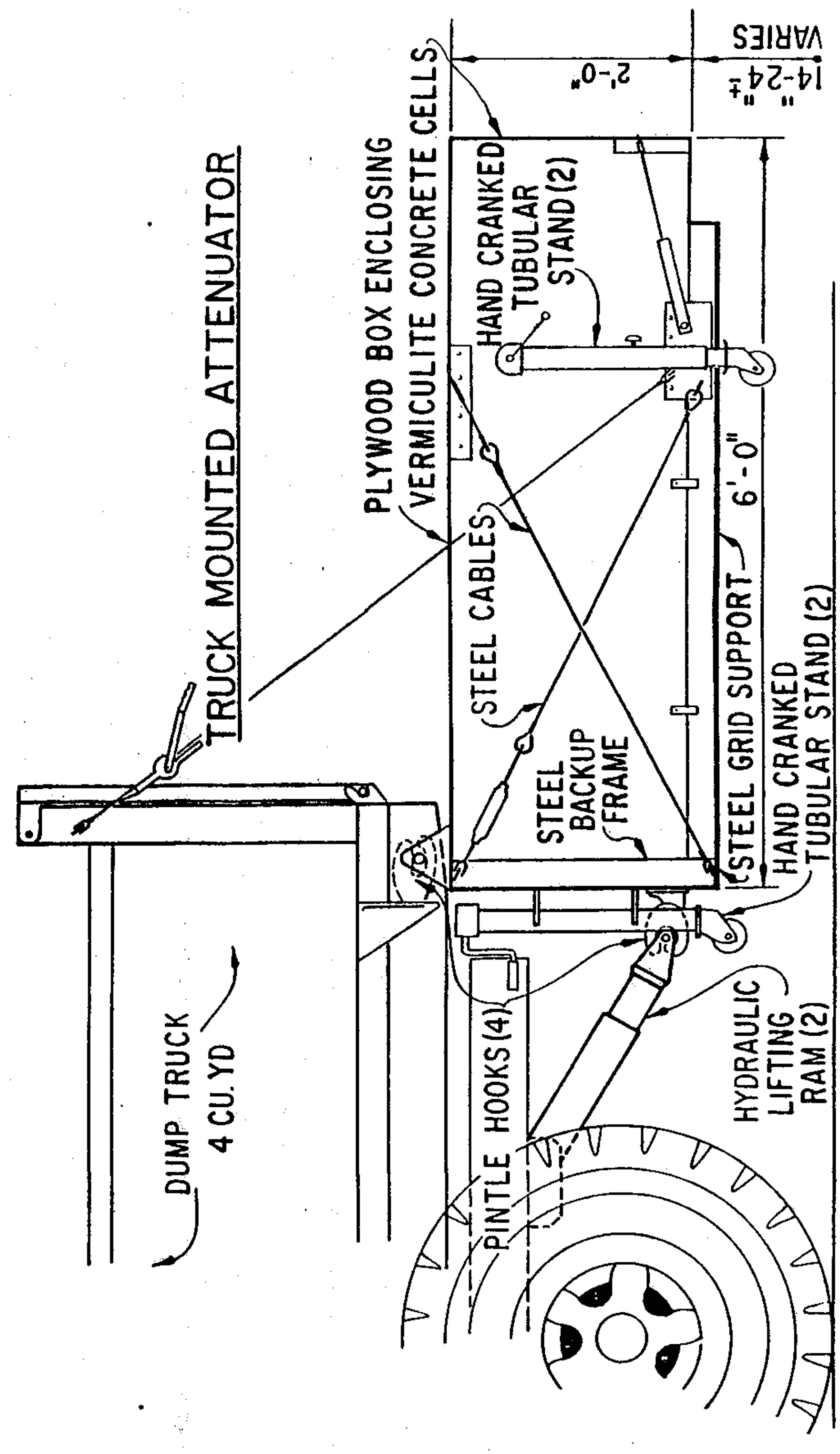
5.1.1 Test Facility

All six vehicular impact tests on the TMA were conducted at the Caltrans Dynamic Test Facility in Bryte, California near Sacramento. The tests took place on a flat asphalt concrete paved surface. The weather was clear, hot and dry for all tests.

5.1.2 Truck Mounted Attenuator Design

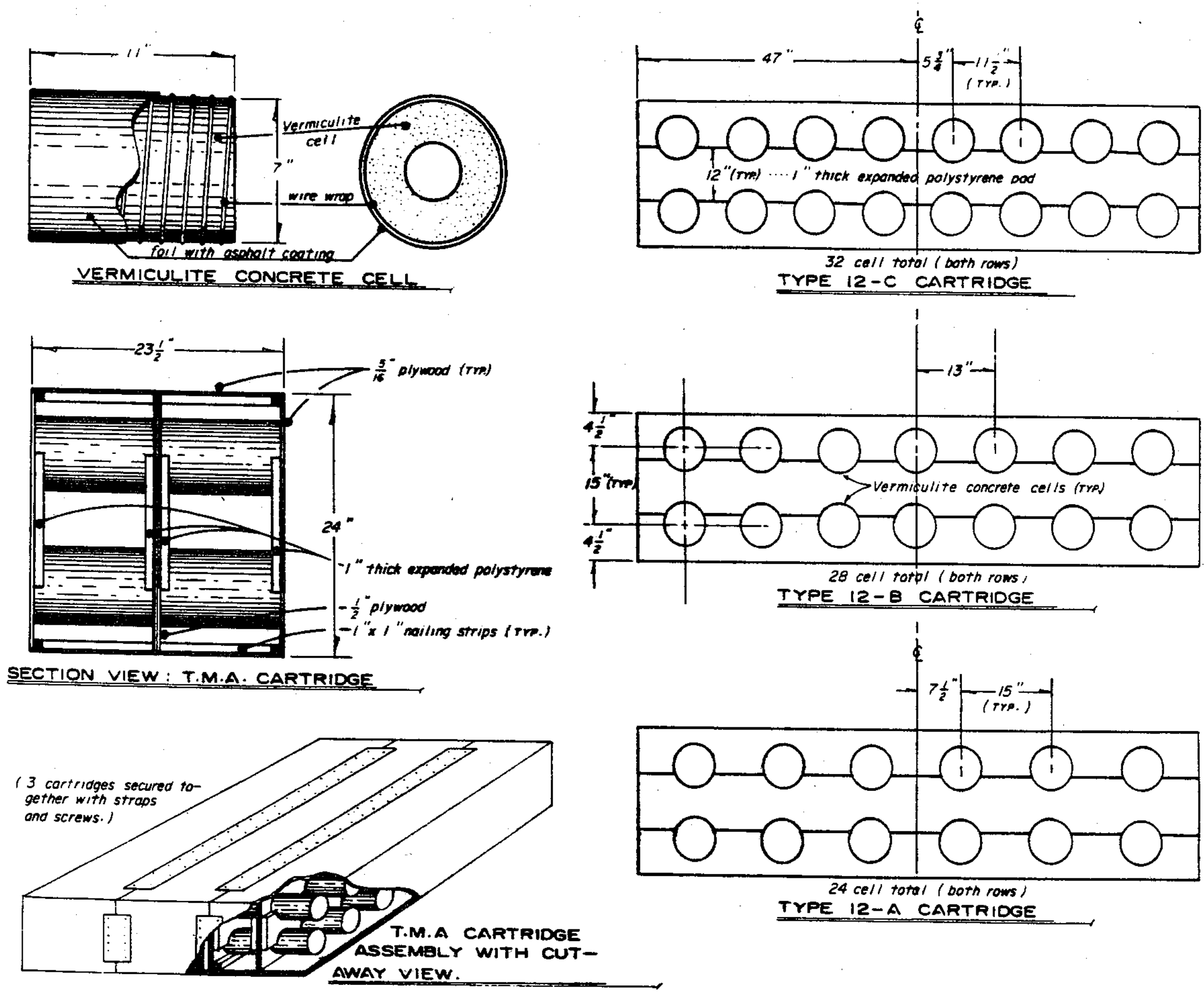
The TMA for the tests in this project weighed about 1400 lbs. and is shown in Figures 1-4. Following is a discussion of the various components and the changes made in them. Most of the components of the TMA were unchanged for these tests.

Plywood Box and Vermiculite Concrete Cells. The crushable vermiculite concrete cells are the energy absorbing component of the TMA. Figure 2 shows the composition of each cell. These cells are the same as those used in the Hi-Dri and G-R-E-A-T highway crash cushions. Reference 9 describes some tests on those cells. For TMA's the cells are mounted in plywood cartridges (Figure 2) eight feet wide by two feet high by two feet deep. Three cartridges were connected in series to form the six-foot-deep TMA. Each cartridge (A, B, and C) had a different layout and number of cells (A-24, B-28, and C-32). The cartridge with the smallest number of cells was placed to the rear (impact



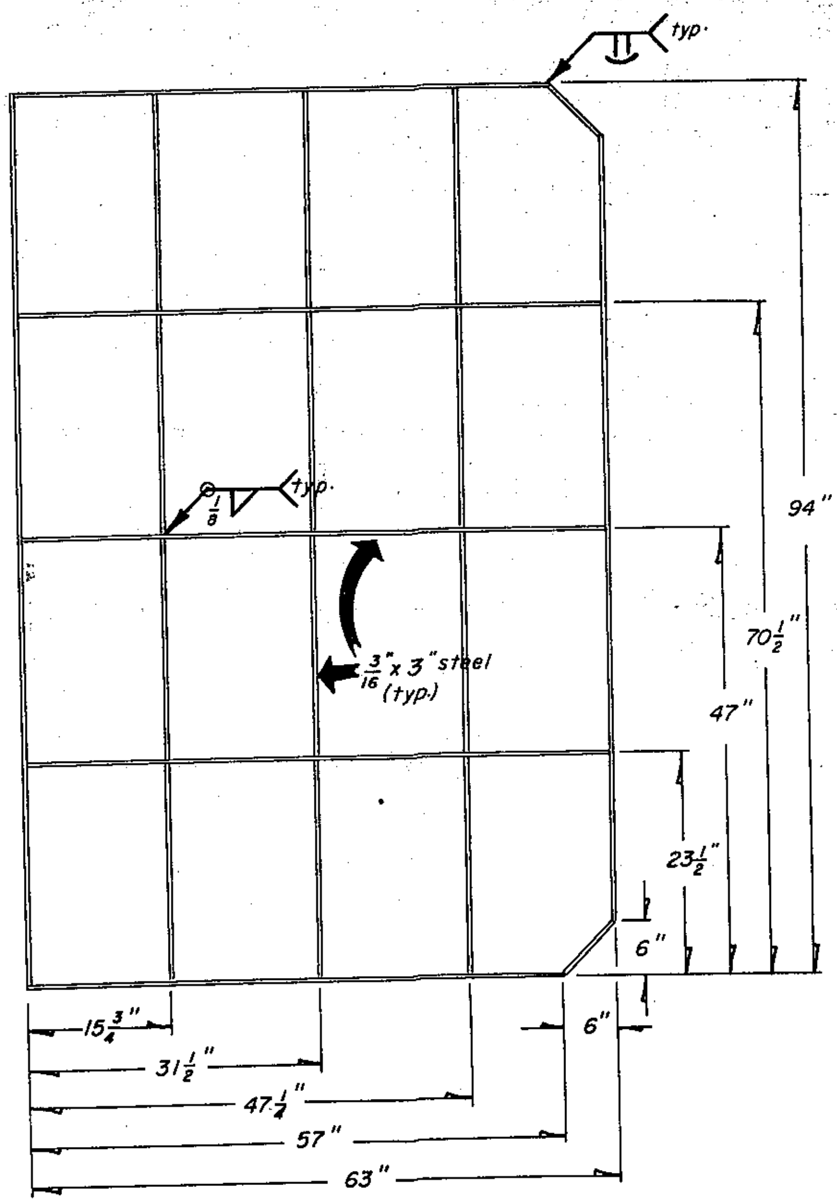
TRUCK MOUNTED ATTENUATOR

Figure I



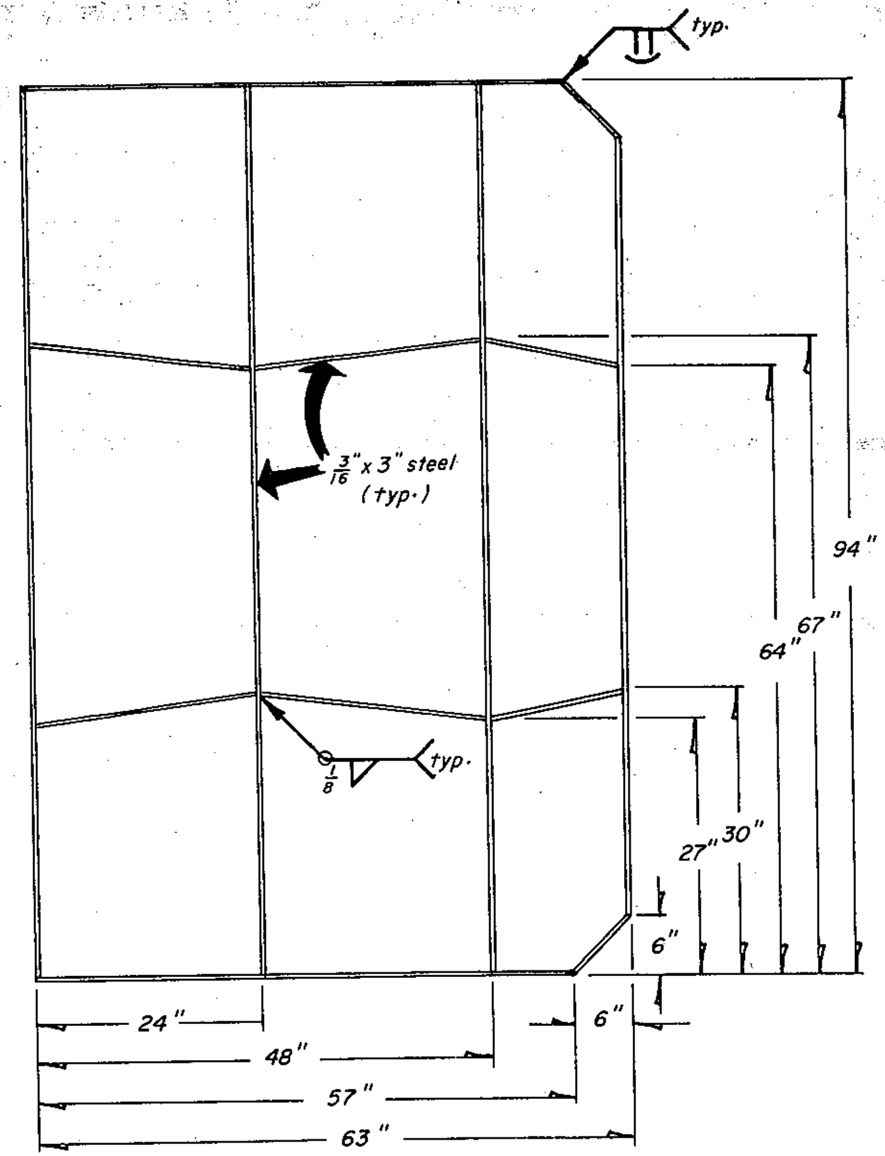
CARTRIDGE DETAILS FOR TRUCK MOUNTED ATTENUATOR

Figure 2



Tests 372, 373, & 374

TOP VIEW



Tests EAS-1 375 & 376

TOP VIEW

STEEL GRID SUPPORTS FOR TRUCK MOUNTED ATTENUATOR

Figure 3

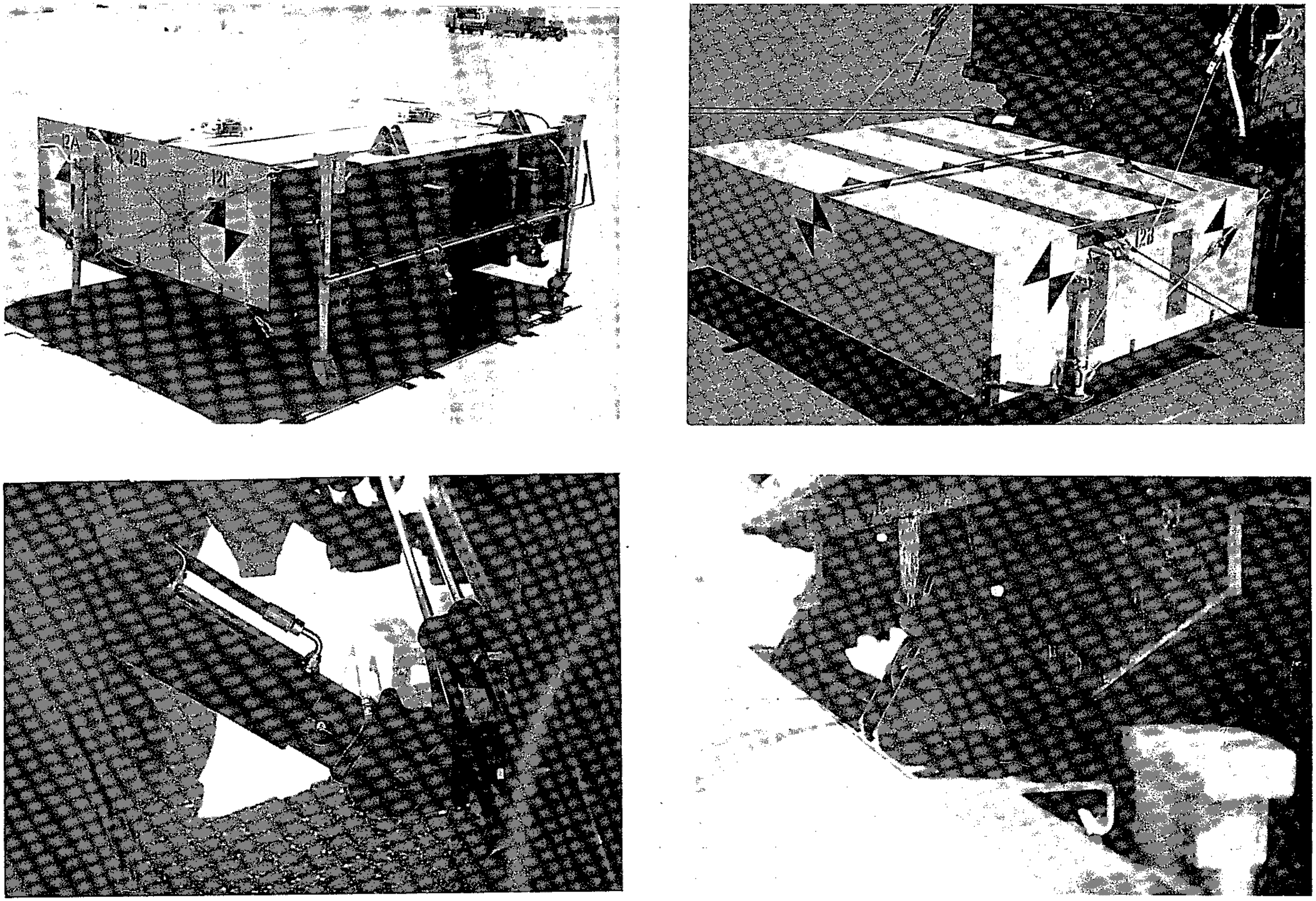


Figure 4

Upper Left: TMA on Support Legs

Lower Left: Hydraulic Lifting Rams Between Truck and TMA

Upper Right: TMA on Truck

Lower Right: Upper Pintle Hooks on Truck With TMA Attached end) to provide a softer initial impact for lightweight cars. More cells in the cartridge near the steel backup frame were needed to progressively stiffen up the TMA for high speed impacts by heavier cars. The cells were glued at each end to the plywood and also supported by one-inch-thick expanded polystyrene cradles. This was done to prevent the cells from breaking loose after extended vibration on the highway and falling down to the bottom of the box. In all tests with the TMA, the ABC arrangement of cartridges was used. Other cartridges patterns could be obtained from the manufacturer.

The plywood covering is stapled together. The cartridges are joined with flat sheet metal straps that are attached to the plywood with a copious number of 1-inch screws. Flat exterior paint was used to protect the plywood from the weather on the test units. Units ordered for field use in the future will have a high gloss exterior-type yellow paint coating.

Steel Backup Frame

The vertical steel backup frame is next to the front TMA cartridge. It forms a strong plane of reaction against which the TMA cartridges can be crushed and is not expected to deform except in severe, high speed impacts. The pintle hook attachment plates, front hand cranked tubular stands, and other brackets are attached to the backup frame.

Steel Grid Support

A steel grid support framework is attached to the steel backup frame to provide vertical support for the TMA cartridges. It was intended that this framework should buckle forward while the TMA cartridges were being crushed. Figure 3 shows the original design used for Tests 372-374 and a more flexible design used for the remaining tests. This latter design is now the standard. Diagonal cables on the sides of the TMA span between the steel grid support and other steel plates, to stiffen the TMA assembly.

The TMA cartridges, steel backup frame, steel grid support, and diagonal cables were all supplied assembled by EAS. Following is a description of the components designed by the Caltrans Office of Equipment that were needed to attach the TMA to the truck and to manipulate it. The complete drawings for this State furnished hardware are contained in Appendix D.

Hand Cranked Tubular Stands

Four hand cranked tubular stands can be lowered to support the TMA above ground at truck mounting height when the TMA is stored off the truck in a maintenance yard. Two stands are attached to the front side of the backup frame, and two stands are mounted on the side of the TMA near the rearward third point of length.

Originally the front two stands were electrically powered; this type was used for all the crash tests. It was found, however, that there were problems with the powered system, and it was decided they would not be needed often enough to warrant their use. All the drawings in this report show hand cranked stands which are being ordered for use with the TMA's being purchased by the State. The change to hand cranked stands in front should have no effect on the impact performance of the TMA.

The two rear stands on the sides of the TMA will normally be oriented in a horizontal direction but can be rotated 90° when the stands are lowered to support the TMA. On the test units, these rear stands were set permanently in a vertical position.

Pintle Hook Attachments

Four pintle hooks are set in a rectangular pattern to make the attachment between the TMA steel backup frame and the back of the truck. A long horizontal rod in front of the backup frame with a lever on each side of the TMA is used manually to release the bottom two pintle hooks. A similar rod and levers are provided to release the upper two pintle hooks.

Hydraulic Lifting Rams

The two hydraulic lifting rams extend down diagonally from the frame of the truck under the dump body to the two lower pintle hooks. In addition to supporting the TMA, the rams can be extended. This causes the entire TMA to rotate about the pins in the two upper pintle hooks and raises the lower rear corners of the TMA from 14 inches to 24 inches above ground. The TMA would be placed in this raised position when the truck was traveling over steep driveways or other locations with abrupt slope changes where the TMA might strike the ground.

Cable and Come-Along

The cable and come-along on each side of the TMA connects the top rear corner of the dump body with a steel plate on the steel grid support frame where the TMA diagonal cables are also anchored. They provide additional support, and the slack can be taken out of the cable with the come-along. It could also be used manually to raise the TMA instead of using the hydraulic lifting rams. The cables and come-alongs were installed for Tests 372-374 and EAS-1. For Tests 375 and 376 they were eliminated because it was thought they were redundant with the hydraulic rams. However, they were replaced on the contract drawings for the new operational units being purchased.

5.1.3 Test Vehicles

Following is a list of the passenger cars used for the tests:

Test No.	Description	Total Weight (lbs)	Steel Plate Ballast Weight (lbs)
371	1971 American Motors Matador, 4-door Sedan	4480	717
372	"	4400	717
373	"	4420	717
374	1972 Ford Pinto Coupe	2140	-0-
*EAS-1	1972 Ford Pinto Coupe	2250	-0-
375	1970 Plymouth Belvedere, 4-door Sedan	4360	717
376	1972 Datsun 1200 Coupe	1890	-0-

*Test conducted independently by Energy Absorption Systems, Inc.

The total weight of the cars includes the weight of the steel plate ballast, on-board instrumentation (about 160 lbs), and the 165 lb dummy. The gas tanks were filled with water for Tests 371-373, and 375.

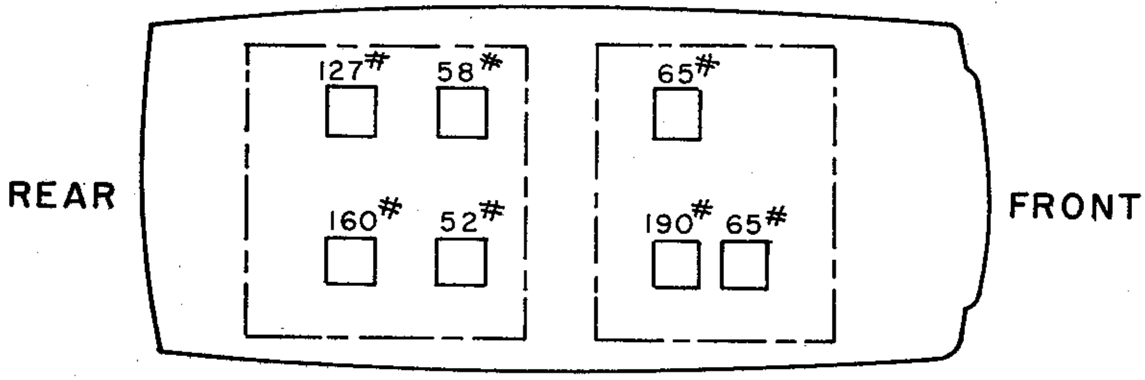
The steel plate ballast was added in some test vehicles to achieve vehicle weights in the range specified in TRC 191 (1). The steel plates were bolted securely to the floorboards and distributed front and back so that the weight distribution on the front and rear wheels would not be changed markedly as shown in Figure 5. The steel plates were slightly below the vertical center of gravity height above ground of the cars.

All of the cars except the Pinto and Datsun were retired State vehicles. They were all in good running condition and free of body damage and missing structural parts.

Although the State vehicles were more than the six year maximum age as recommended in Reference 1, the researchers believed the use of newer vehicles would not have changed the test results in any significant way. All of the cars had rear wheel drive and longitudinal engine mounting.

All vehicles were self-propelled. Steering control was achieved with a straight anchored guidance cable running through a bracket attached to the right front wheel. No constraints were placed on the steering wheel. A short distance before the point of impact, the vehicle ignition was turned off, and the car was released from the guidance cable. A speed control device on the car maintained the desired impact speed once it was attained.

Details of the car equipment are contained in Appendix A.



Ballast Weights and Locations

Figure 5. Steel Ballast Plates Bolted to Floor in Rear Passenger Compartment For Tests 371, 372, 373, and 375

Following is a list of the trucks used for the tests:

Test No.	Description	Truck Weight* (lbs)
371	Ford F750 with 4 cu yd dump body, **GVW = 25,000 lbs	11,600
372,373,375,376 EAS-1	"	11,740
374	"	11,900***

*Truck weight includes TMA mounting hardware and controls (Tests 372-376), but not TMA.

**GVW = Gross vehicle weight capacity, truck loaded.

***Includes weight of dummy in truck cab used this test only.

Two identical trucks were used for the test series. The same truck was used for Tests 372-376. The trucks were both retired Caltrans vehicles, in running condition, free of body damage and missing structural parts, and unmodified for the tests, except for the TMA mounting hardware described in Section 5.1.2.

In each of the six passenger car impact tests the truck was parked with the transmission in second gear. Rather than using the spring actuated rear wheel parking brakes, all four brakes were locked by depressing the brake pedal in Tests 371, 372, 374 and EAS-1. In Tests 373 and 376 only the rear wheel parking brakes were applied. In Test 375 it was intended to use the air brakes for all wheels, but a leak developed just before the test so the air brakes were used on the front wheels only and the parking brakes on the rear wheels. The truck engine was run before impact to build up air pressure in the brake system reservoir. Since the trucks were old and had leaky brake systems, the truck engine was shut off within five minutes of impact to insure that there was sufficient air pressure to hold the brakes. Four wheel braking was used for most of these tests because the Office of Equipment intended to modify all trucks that would have TMA's so that they could use four wheel braking when parked along the roadway.

Two lightweight steel tube frames with targeting were cantilevered off the top of the dump body of the truck. They permitted smaller more detailed fields of view in the data cameras without sacrificing the means to plot the truck displacement and velocity.

5.1.4 Data Acquisition Systems

Several high speed movie cameras were used to record the impact events. A normal speed movie camera, a video camera, and a colored slide camera were used also to picture the impact and the conditions of the test vehicles and TMA's before and after the impact. In addition black and white still photography was used to cover pre- and post-impact test conditions.

Accelerometers were mounted on the floorboard of the car at the c.g. and on the floorboard in the truck cab. Acceleration data were collected to judge impact severity and the chance of passenger injuries or fatalities.

An anthropomorphic dummy with accelerometers mounted in its head cavity was placed in the driver's seat of the passenger car to obtain motion and acceleration data. The dummy, Willie Makit, a Part 572 dummy built to conform to Federal Motor Vehicle Safety Standards by the Sierra Engineering Co., is a 50th percentile American male weighing 165 lbs. The dummy was restrained with a standard lap and shoulder belt for all tests except Test 376 where only the lap belt was used. The dummy used in the truck cab in Test 374 was Sierra Stan, Model P/N 292-850 manufactured by the Sierra Engineering Co., also a 50th percentile male.

A sliding weight device was attached to the right side of the car. Upon impact the weight, fitted with ball bearings, slides two feet forward on a smooth rod. This was used to calculate the rattlespace time, the time required for the weight to slide forward two feet. This is another measure of impact severity.

Appendices B and C contain a detailed description of the photographic and electronic equipment, camera and accelerometer layout, data collection and reduction techniques, and accelerometer records.

5.1.5 Test Parameters

Following are the parameters for the test vehicles:

Test Cars

Test No.	Car Wt.(lbs)	Speed (mph)	Angle (degrees)
371	4480	45	0° Head-on
372	4400	45	0° Head-on
373	4420	45	0° Head-on
374	2140	45	0° Head-on
EAS-1**	2250	49	0° Head-on
375	4360	45	15°, 3 ft Offset
376	1890	44	0° Head-on

Test Trucks

Test No.	Truck Wt. w/o TMA (lbs)	TMA on Truck	TMA Wt.(lbs)	Brakes Set
371	11,600	No	-	All wheels, air brakes
372	11,740	Yes	1400	All wheels, air brakes
373	11,740	Yes	1400	Rear wheels, parking brakes
374	11,900*	Yes	1400	All wheels, air brakes
EAS-1**	11,740	Yes	1400	All wheels, air brakes
375	11,740	Yes	1400	Front wheels, air brakes Rear wheels, parking brakes
376	11,740	Yes	1400	Rear wheels, parking brakes

*The higher truck weight was due to a dummy in the truck cab in this test only.

**Impact test conducted by Energy Absorption Systems to provide supplemental data on revisions to the steel grid support.

For all tests the trucks were parked with the transmission in second gear and hit from the rear. The TMA's were all identical production units, except for a change in the steel grid support used in Tests EAS-1 and 375-376, described elsewhere.

5.2 Test Results

Accelerometer records from the cars, trucks, and head of the dummy are contained in Appendix C. A film report has been assembled which shows all six Caltrans tests.

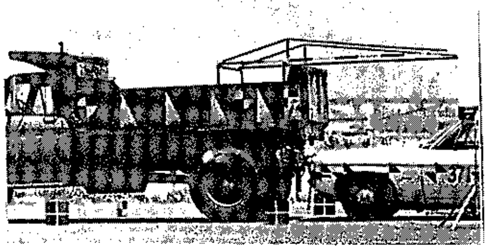
5.2.1 Test 371 Car-4480 lbs/45 mph/0° head-on
Truck-11,600 lbs/all wheels braked/No TMA

The summary of test data and photos of the vehicles before and after impact are shown in Figures 6 through 8.

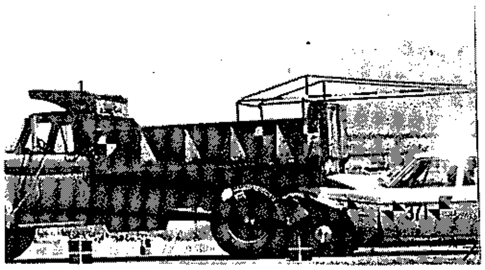
5.2.1.1 Impact Description - 371

The car struck the truck at the intended speed and angle. The car was 9 inches off center to the left of the truck centerline. The front of the car was severely crushed and compressed against the undercarriage of the truck before the truck began to move. Initially, after impact, the truck bed was forced upward and the rear wheels were lifted a few inches off the ground as the truck moved forward. During this time, the rear wheels did not turn until they made contact with the ground again. The rear wheels rotated 88°. The front wheels on the truck rotated during the entire forward movement of the truck, a total of over 180°. After the maximum compression of the front end of the car occurred, the car appeared to re-extend slightly due to the storage of elastic energy. However, the car

Figure 6. Data Summary Sheet - Test 371



Impact + 0.00 Sec



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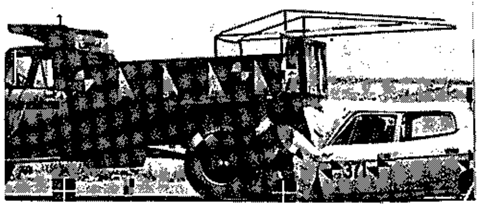
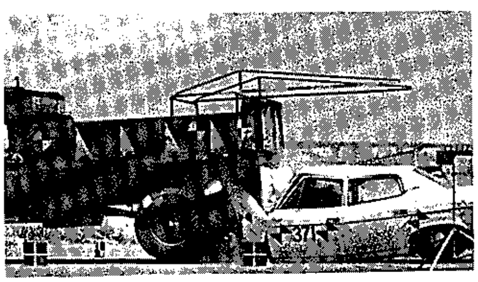
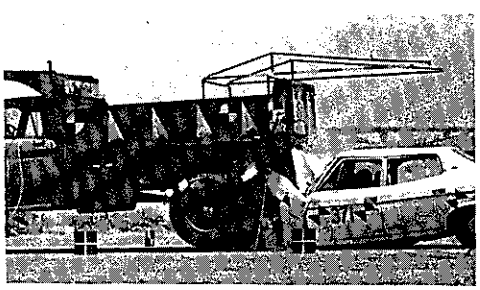


I + 0.14 Sec



I + 0.31 Sec



I + 1.83 Sec

Test Date	June 21, 1979

Truck Mounted Attenuator Data

Type	Not used this test.
Size	
Weight	

Truck Data

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Air, All Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,600 lbs.

Car Data

Model	1971 Amer.Mtrs.Matador Sedan
Impact Velocity	45 mph
Impact Angle	0°
Weight	4,480 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

Impact Data

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	-21.5g
Truck, Longitudinal	5.0g
Dummy Head, Resultant (no vert)	-39.2g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-4.9g
Max. Car Pass.Compart.Decel.Dist.,s	13.9 ft
Truck Roll Ahead Distance	10.3 ft
Max. Pitch, Car (Rear End)*	-8.0°
Max. Rise, Truck Dump Body Rear	10.0 in.
TAD/VDI Index, Car	FD-7/12FDEW6

*Pitch was less at the front end because the car buckled in the middle.

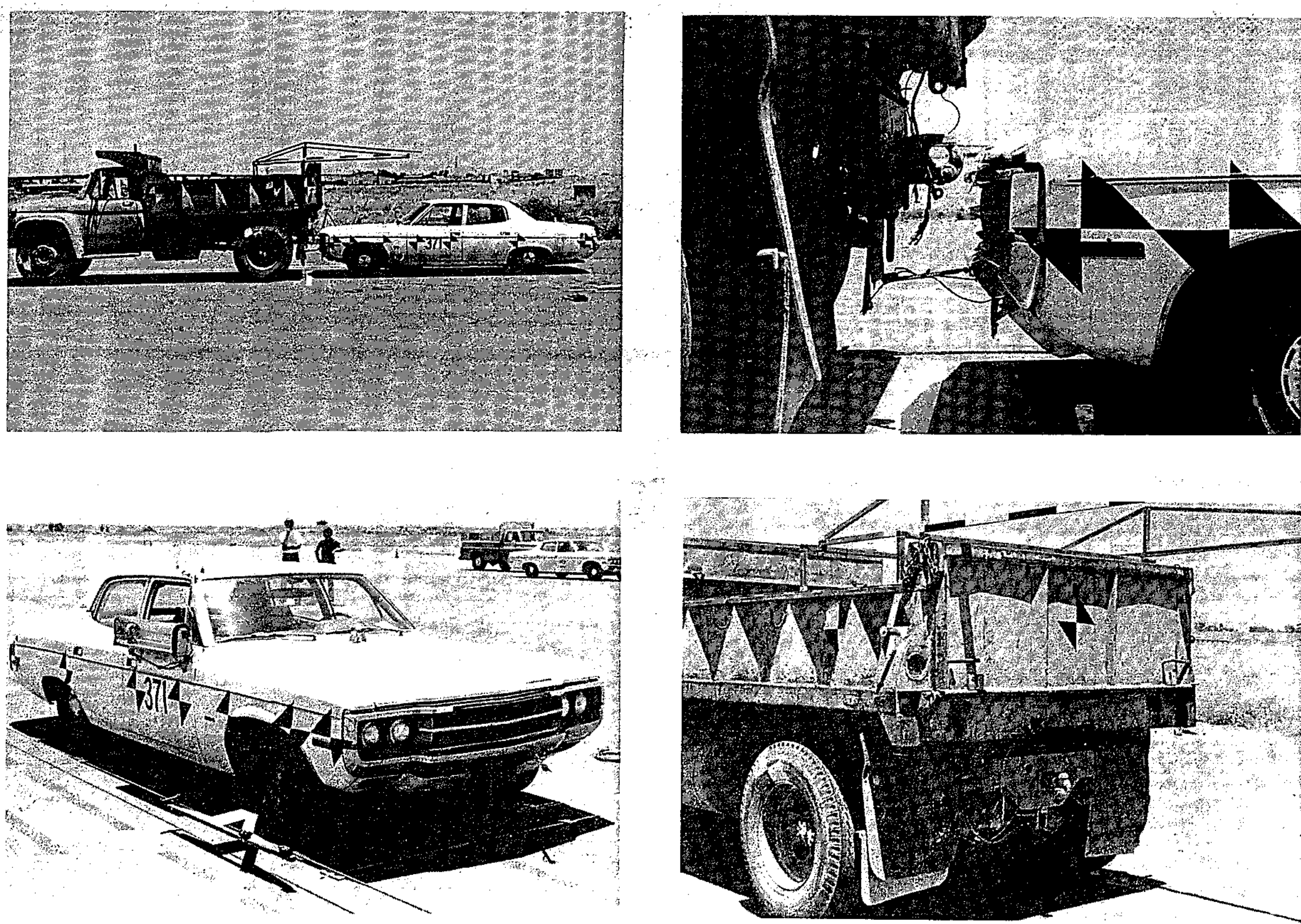


Figure 7. Test 371. Test vehicles before impact. Lower left photo shows cable guidance bracket attached to wheel.

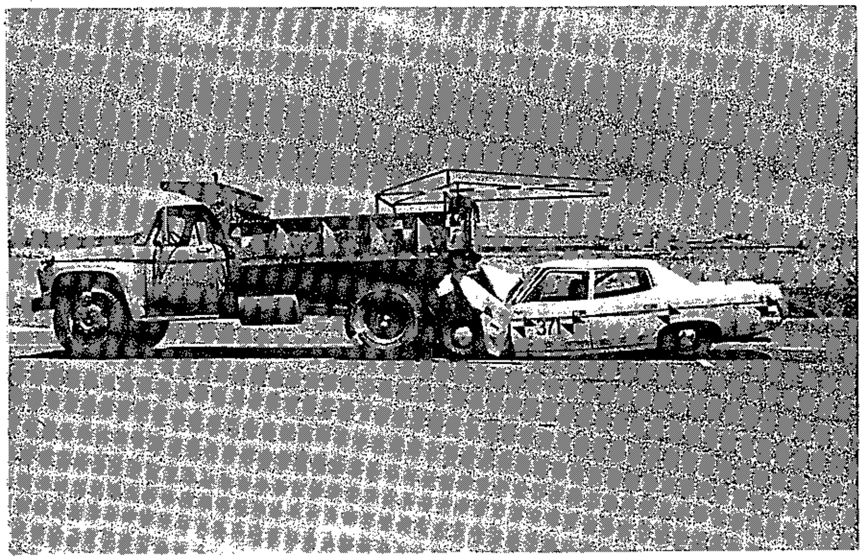
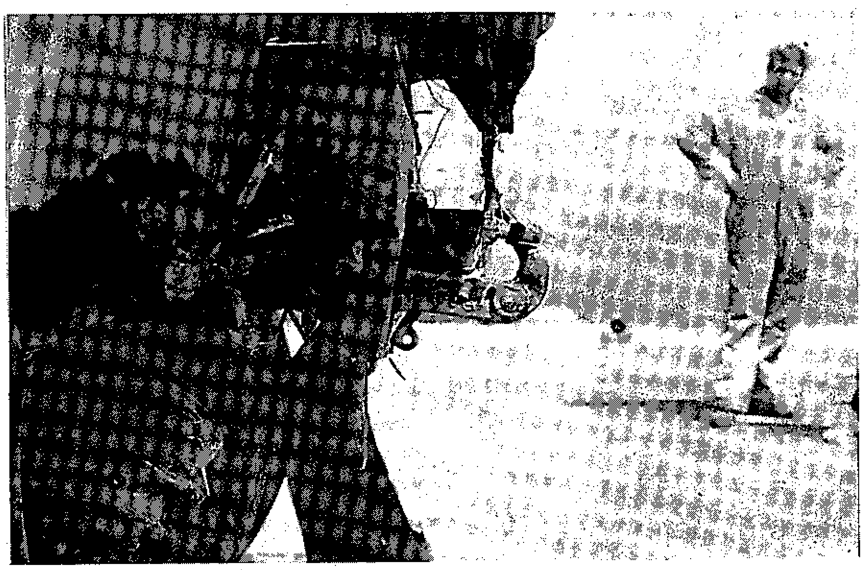


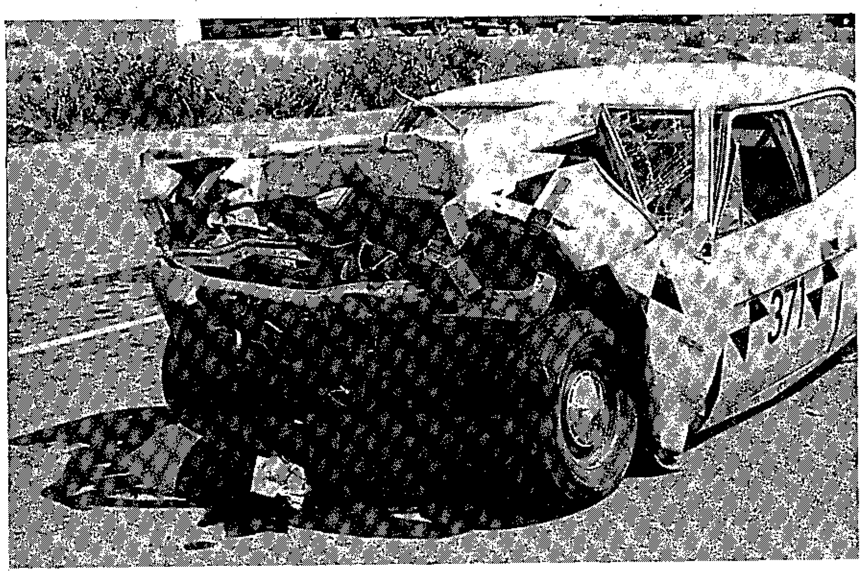
Figure 8.

Test 371

Test Vehicles
After Impact



Pintle Hook at Rear
End of Truck



was hooked onto the truck and traveled with it to a stop. The truck moved forward a total of 10 ft 4 in. There was minimal yawing and pitching of the car during impact.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -21.5 G's. The comparable value of longitudinal acceleration in the cab of the truck was 5.0 G's.

5.2.1.2 Car Damage - 371

Damage to the car was quite extensive. The front end was severely crushed a maximum of approximately 19 inches at a height of 24 inches above ground. The hood was crushed back a maximum of 37 inches. The windshield was broken by the hood, the radiator was crushed back to the fan, all four doors were jammed, the roof over the doorposts was crimped indicating buckling in the car body as a whole, the engine moved back slightly, and the tires were restricted against movement. The car could not have been driven or rolled away from the test site. The dashboard and steering column were pushed a short distance into the passenger compartment, but otherwise there was no intrusion of vehicle parts. Buckling in the floorboard damaged one of the accelerometers. The steel ballast plates remained attached.

5.2.1.3 Truck Damage - 371

Damage to the truck was relatively light. The rear cross member, differential cover, and rear springs were bent. A rear brake actuator was torn loose from its location near the inside face of the rear tire, and the brake lines were ripped loose. Although the truck could be driven, there must have been some damage to the drive train because it did not operate smoothly.

5.2.1.4 Dummy Behavior - 371

Although the dummy was restrained with a lap and shoulder belt, it received a sharp blow to the chin when it hit the steering wheel. The steering wheel was permanently deformed a maximum of two inches away from its original plane. Indentations were made at the bottom edge of the dashboard where the dummy's knees slammed into it.

5.2.2 Test 372 Car-4400 lbs/45 mph/0° head-on
Truck-11,740 lbs/all wheels braked/
plus TMA-1400 lbs

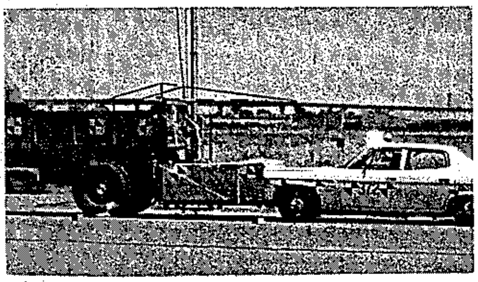
The summary of test data and photos of the vehicles before and after impact are shown in Figure 9 through 11.

5.2.2.1 Impact Description - 372

The car struck the TMA on the truck at the intended speed and angle. The TMA crushed readily. The car, being narrower than the TMA, passed inside the plywood side panels of the TMA. The three top panels of the TMA were more or less stacked as they were thrown against the back of the truck by the front of the car. They barely touched the windshield of the car at the right front windshield post for a few instants.

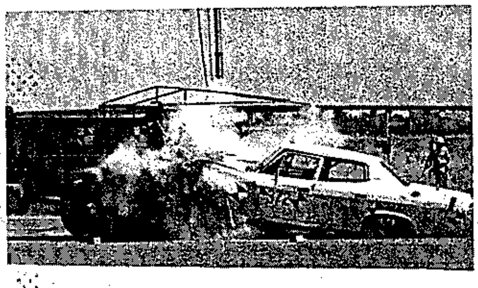
The car crushed through practically the entire 6 ft 0 in. length of the TMA before the truck began to move. Ultimately,

Figure 9. Data Summary Sheet - Test 372

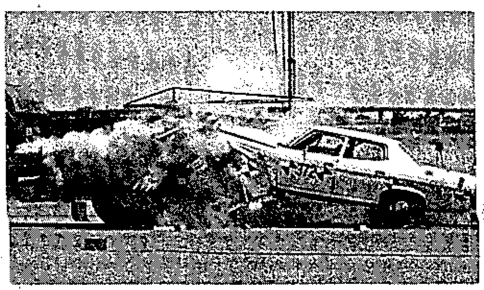


Impact + 0.02 Sec

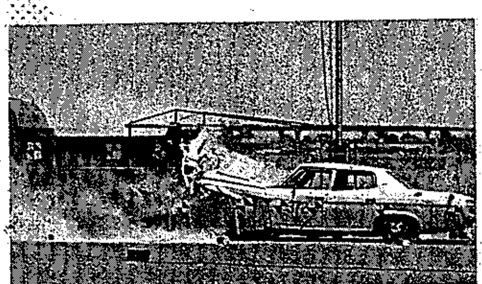
I + 0.09 Sec



I + 0.22 Sec



I + 0.48 Sec



I + 2.97 Sec

Test Date — July 19, 1979

Truck Mounted Attenuator Data

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1,400 lbs.

Truck Data

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rate 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Air, All Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,740 lbs.

Car Data

Model	1971 Amer.Mtrs.Matador Sedan
Impact Velocity	45 mph
Impact Angle	0°
Weight	4,400 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

Impact Data

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	-9.7g
Truck, Longitudinal	3.5g
Dummy Head, Resultant	-21.5g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-4.9g
Max. Car Pass.Compart.Decel.Dist.,s	13.9 ft
Truck Roll Ahead Distance	7.9 ft
Max. Pitch, Car	-10.0°
Max. Rise, Truck Dump Body Rear	5.7 in.
TAD/VDI Index, Car	FD-5/12FDEW5

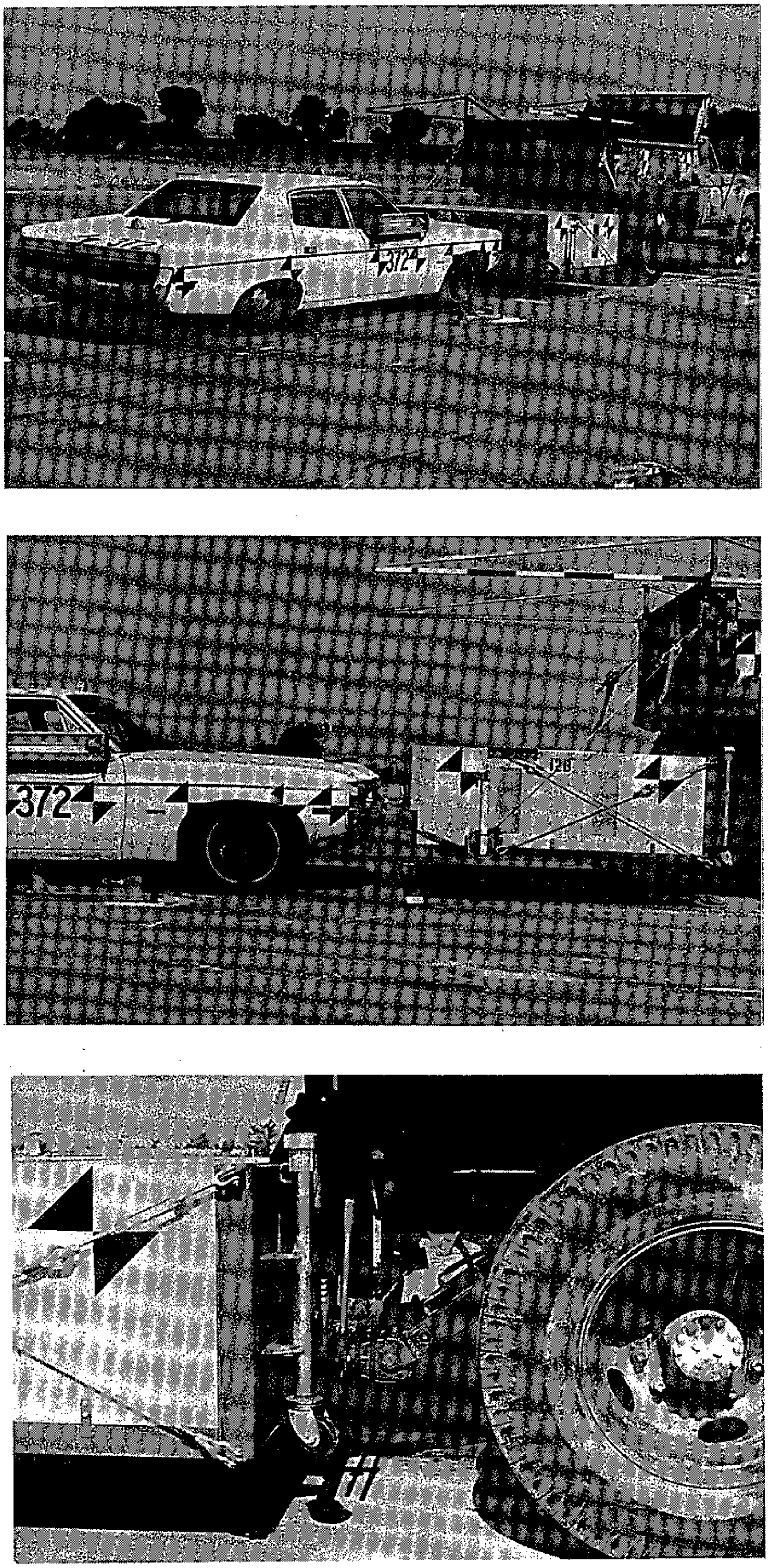


Figure 10.

Test 372

Test Vehicles and
TMA Before Impact

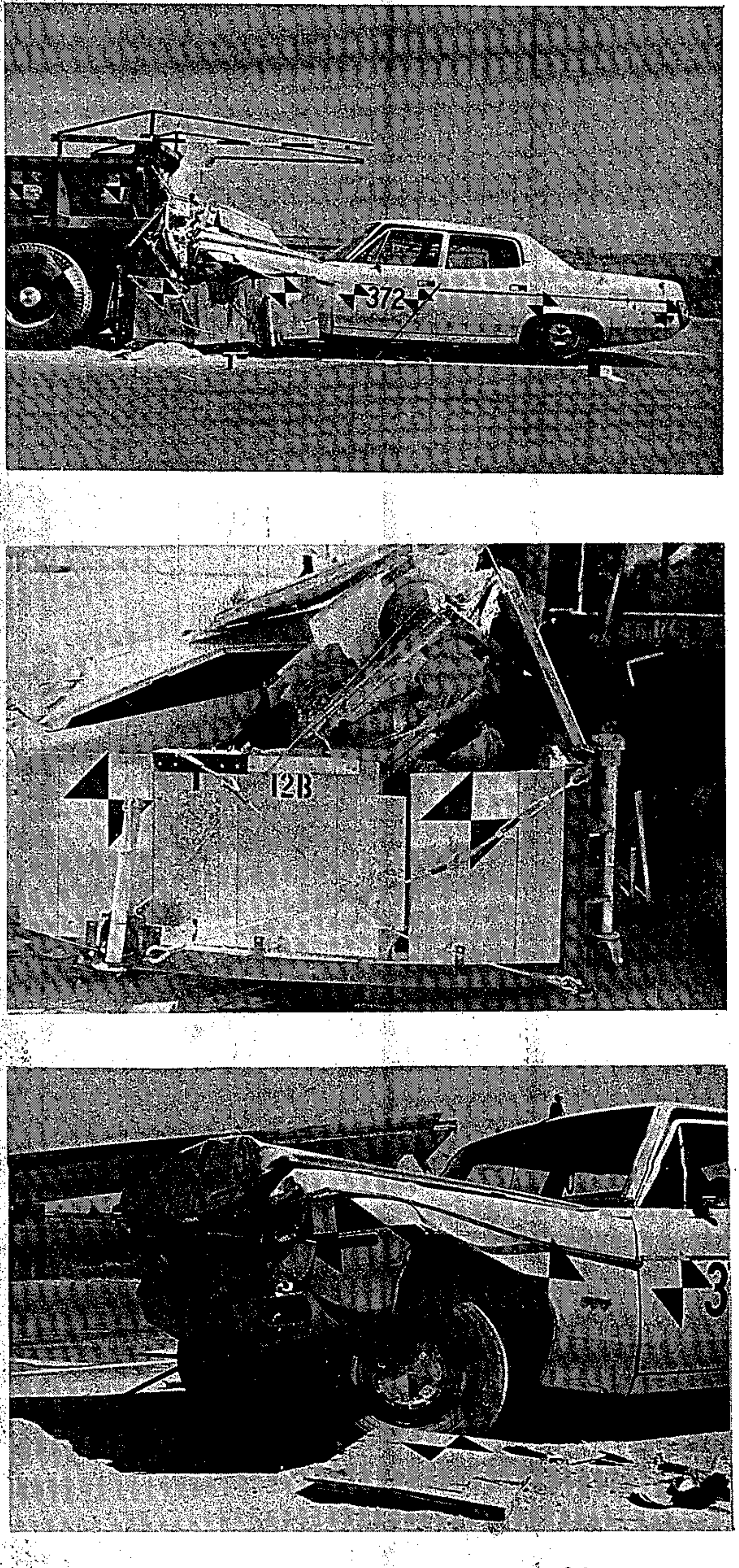


Figure 11.

Test 372

Test Vehicles and
TMA After Impact

the truck moved straight ahead 7 ft 11 in. After the car had smashed through most of the length of the TMA, the front end of the car began to rise. Concurrently the back end of the truck rose a short distance. The maximum rise of the two vehicles occurred midway through the truck movement. The back end of the dump body on the truck rose a maximum of 5.7 inches. The maximum pitch of the car at this time was -10°. There was virtually no yawing or rolling of the car which stayed in contact with the truck after impact. Due to the dust generated by the impact with the TMA, it was difficult to determine how much the truck wheels moved. It appeared that the left front wheel turned at least 180° during the truck movement and one rear wheel turned 110°.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -9.7 G's. The comparable value of longitudinal acceleration in the cab of the truck was 3.5 G's.

5.2.2.2 Car Damage - 372

Damage to the car was severe but less than in Test 371. The front end was uniformly crushed back, a maximum of 16 inches at a height of 24 inches above ground. The hood was crushed back a maximum distance of 15 inches at a height of 44 inches above ground.

The radiator was crushed back to the fan, the engine did not move, the windshield was cracked, all four doors were jammed, the left and right doorposts were deformed, the roof over the door posts was crimped, and the right front tire was flat. The car could not have been driven or rolled away from the test site. There was no intrusion of vehicle parts or barrier components into the passenger compartment.

5.2.2.3 Truck Damage -372

Truck damage was very light. One brake actuator was broken by the attenuator support.

5.2.2.4 TMA Damage - 372

Almost all the energy absorbing capacity of the TMA was used. Only one or two vermiculite concrete cells were not crushed. The outer plywood panels on the TMA were crushed and splintered.

Debris around the impact area was minimal. Small pieces of plywood with a maximum long dimension of 1 ft 0 in. were scattered around the TMA up to 8 feet out from the truck; however, the number of pieces was few, most pieces were small, and most were close to the truck. There was a thin layer of dust and crumbled vermiculite concrete around the truck.

The steel support frame under the TMA box was not reusable but the steel plate backup structure was salvaged. The TMA supports and controls mounted on the back of the truck incurred light damage. The upper control lever for the pintle hooks was bent. The upper truck mounting for the attenuator yielded which caused the backup structure on the TMA to move downward. This mounting was strengthened with a steel brace for Test 373.

The TMA was dismantled before measurements of the crush profile could be taken.

5.2.2.5 Dummy Behavior - 372

Although the dummy struck its chin on the steering wheel, the wheel was not bent out of its original plane. The steering column was forced down 3/8 inch at the point where it goes through the dashboard. The dummy also hit its knees on the dash which caused minor cracking of the thin plastic molding.

5.2.3 Test 373 Car-4420 lbs/45 mph/0° head-on Truck-11,740 lbs/rear wheels braked/ plus TMA-1400 lbs

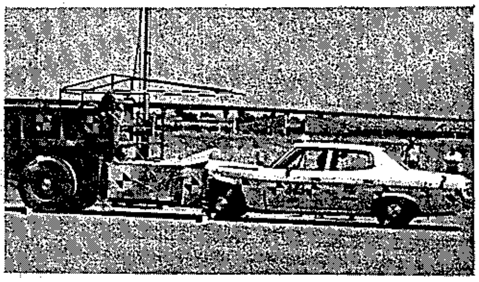
The summary of test data and photos of the vehicles after impact are shown in Figures 12 and 13.

5.2.3.1 Impact Description - 373

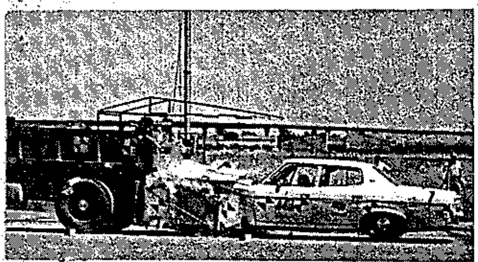
The car struck the TMA on the truck at the intended speed and angle. The TMA crushed easily. The car passed inside the plywood side panels of the TMA. The hood of the car nosed under the top plywood panel of the TMA. Eventually this top panel barely made contact with the windshield which cracked over a small area near the bottom. Had the TMA been longer, the top panel might have been more damaging to the windshield.

The passenger compartment of the car moved roughly 6 ft 0 in. ahead after initial impact with the TMA, while the truck only moved a few inches during attenuator penetration. The final roll ahead distance for the truck was 13 ft 10 in.

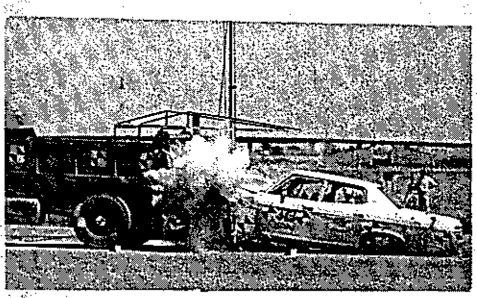
Figure 12. Data Summary Sheet - Test 373



Impact + 0.04 Sec



I + 0.10 Sec



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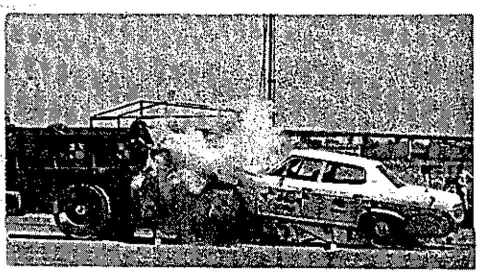

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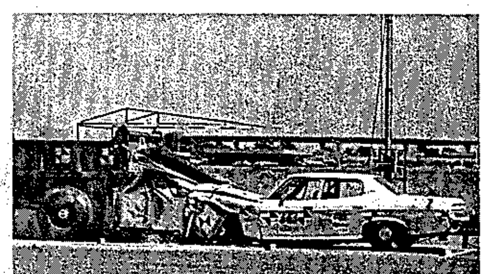


I + 5.61 Sec

Test Date	August 1, 1979

Truck Mounted Attenuator Data

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1,400 lbs.

Truck Data

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Parking br., Rear Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,740 lbs.

Car Data

Model	1971 Amer.Mtrs.Matador Sedan
Impact Velocity	45 mph
Impact Angle	0°
Weight	4,420 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

Impact Data

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	-10.8g
Truck, Longitudinal	4.3g
Dummy Head, Resultant	-18.4g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-3.8g
Max. Car Pass.Compart.Decel.Dist.,s	18.0 ft
Truck Roll Ahead Distance	13.8 ft
Max. Pitch, Car	-7.8°
Max. Rise, Truck Dump Body Rear	4.4 in.
TAD/VDI Index, Car	FD-5/12FDEW5

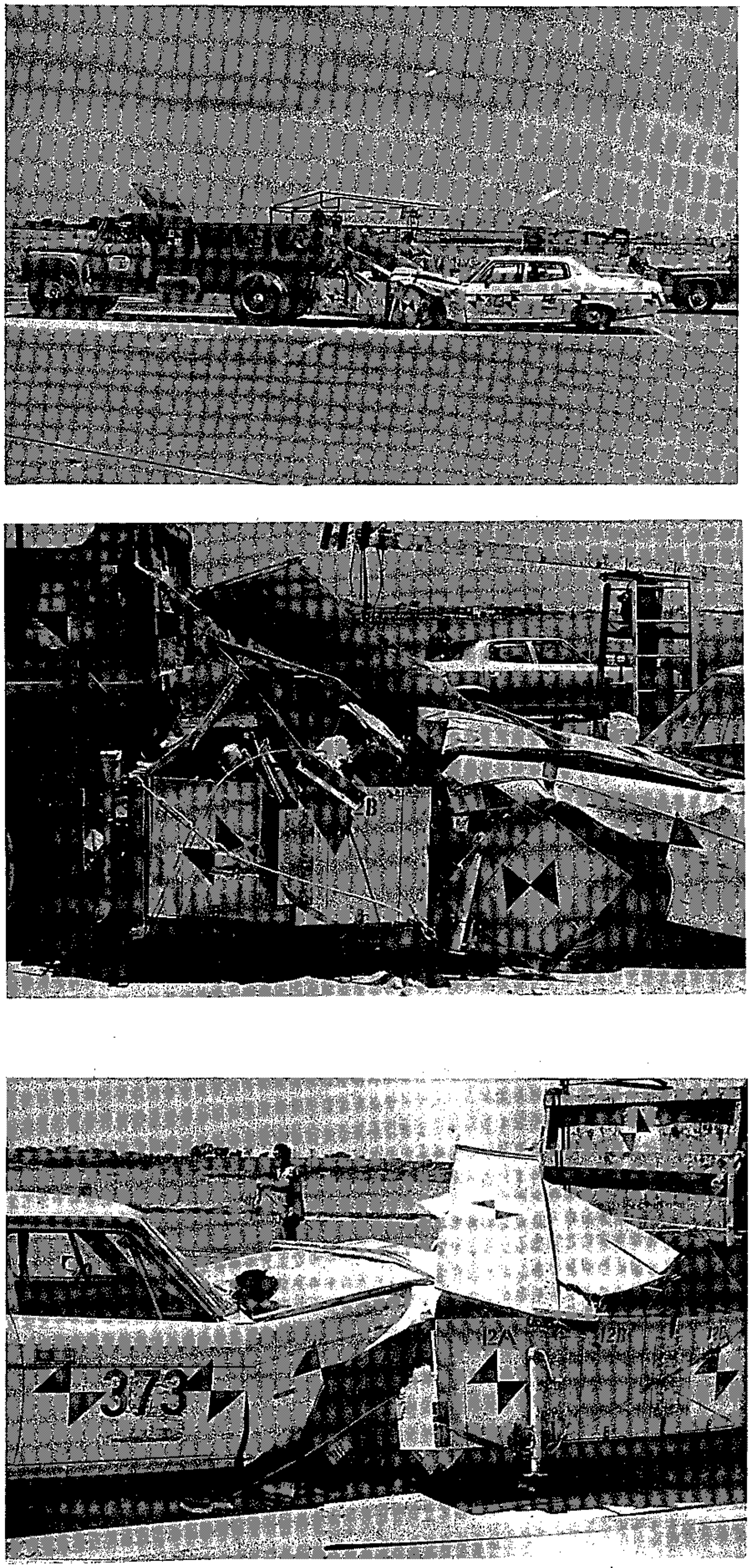


Figure 13.

Test 373

Test Vehicles and TMA After Impact

After the car had smashed through most of the length of the TMA, the front end of the car began to rise. Concurrently, the back end of the truck rose a short distance. The maximum rise of the two vehicles occurred midway through the truck movement. The back end of the dump body on the truck rose a maximum of 4.4 inches. The maximum pitch of the car at this time was 7.8°. There was virtually no yawing or rolling of the car which stayed in contact with the truck after impact. It was difficult to determine from the test movies how much the truck wheels rotated. The unbraked left front wheel appeared to turn, rather than skid, all the time the truck was moving. The braked left rear wheel appeared to rotate during some of the truck movement, but stopped rotating when the car forced the rear end of the truck upwards, thus relieving some of the weight on the rear wheels. Rear wheel rotation was measured as 298°.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -10.8 G's. The comparable value of longitudinal acceleration in the cab of the truck was 4.3 G's.

5.2.3.2 Car Damage - 373

Damage to the car was severe but less than in Test 372 and much less than in Test 371. The front end was uniformly crushed back a maximum of 9 inches at a height of 24 inches above ground. The hood was crushed back a maximum distance of 11 inches at a height of 44 inches above ground.

The front frame members under the engine were bent slightly, the radiator was crushed back to the fan, the engine did not move back, the windshield was cracked, all four doors were jammed, and the roof over the door posts on the left side was crimped slightly. The tires were all intact. The car could not be driven but it did roll because the front wheels were not disabled. There was no intrusion of vehicle parts or barrier components into the passenger compartment.

5.2.3.3 Truck Damage - 373

None.

5.2.3.4 TMA Damage - 373

Almost all of the energy absorbing capacity of the TMA was used up, similar to Test 372. Virtually all the vermiculite concrete cells were crushed. The outer plywood panels were crushed and splintered. Debris around the car and truck was minimal. It consisted of small pieces of plywood and a thin layer of the crumbled vermiculite concrete which were within a few feet of the vehicles. Most of the debris ended up between or beneath the vehicles. The TMA controls on the truck were undamaged and the steel backup frame on the TMA was reusable. The permanent maximum crush of the TMA varied from 29 to 38 inches from the bottom to the top of the unit.

5.2.3.5 Dummy Behavior - 373

The dummy struck its chin on the steering wheel but did not deform the wheel. The steering column was forced down 1/2 inch at the point where it goes through the dashboard. The dummy also hit its knees on the dash which caused minor cracking of the thin plastic molding.

5.2.4 Test 374 Car-2140 lbs/45 mph/0° head-on Truck-11,900 lbs/all wheels braked/ plus TMA-1400 lbs

The summary of test data and photos of the vehicles before and after impact are shown in Figures 14 through 16.

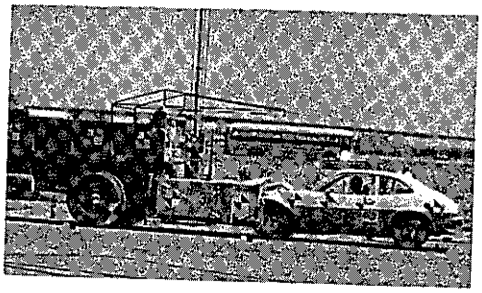
5.2.4.1 Impact Description - 374

The car struck the TMA on the truck at the intended speed and angle. The car passed inside the plywood side panels of the TMA, nosed underneath the top plywood panels on the TMA, and forced down the front section of the bottom panel. The top panels barely grazed the windshield of the car but did not damage it.

There was little truck movement while the car was crushing the TMA. The passenger compartment of the car traveled over six feet after initial impact while the truck traveled a few inches. Eventually, the truck moved ahead a total distance of 2 ft 5 in. During this time the left front wheel of the truck turned very little while the left rear wheel rotated 43°, but did not rotate continuously.

Close to the time the car had finished crushing, the front end began to dive down until the car reached a maximum pitch of 3.5°. The rear end of the car rose slightly but the rear wheels did not appear to lose contact with the ground. This vehicle diving may have been due in part to the resistance the front wheels of the car felt when they ran into the lower steel grid support for the TMA which bent a few inches but was otherwise unyielding. It

Figure 14. Data Summary Sheet - Test 374



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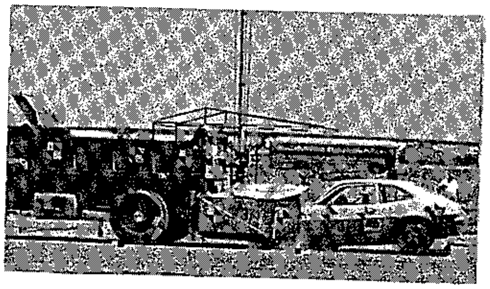

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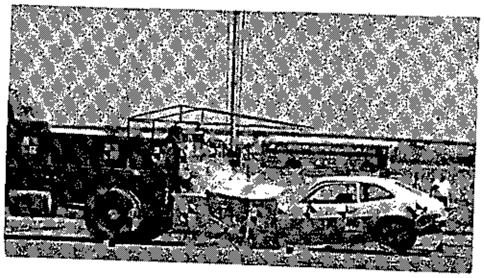
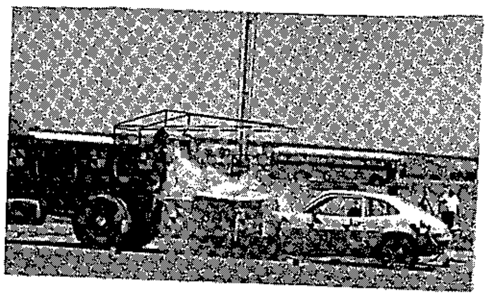
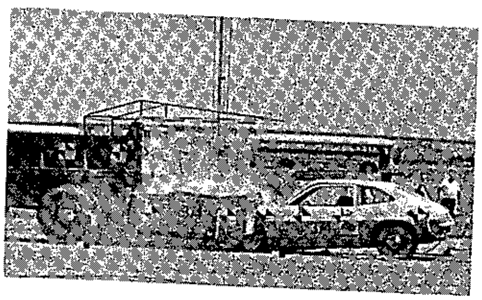


I + 0.24 Sec



I + 0.50 Sec



I + 1.46 Sec

<u>Test Date</u> August 10, 1979

<u>Truck Mounted Attenuator Data</u>

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1,400 lbs.

<u>Truck Data</u>

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Air, All Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,900 lbs.
Dummy Type	Sierra Model P/N 292-850, 50th Percentile

<u>Car Data</u>

Model	1972 Ford Pinto Coupe
Impact Velocity	45 mph
Impact Angle	0°
Weight	2,140 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

<u>Impact Data</u>

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	-14.0g
Truck, Longitudinal	2.4g
Dummy Head, Resultant	-28.3g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-11.1g
Max. Car Pass.Compart.Decel.Dist.,s	6.1 ft
Truck Roll Ahead Distance	2.4 ft
Max. Pitch, Car	+3.5°
Max. Rise, Truck Dump Body Rear	1.1 in.
TAD/VDI Index, Car	FD-5/12FDEW5

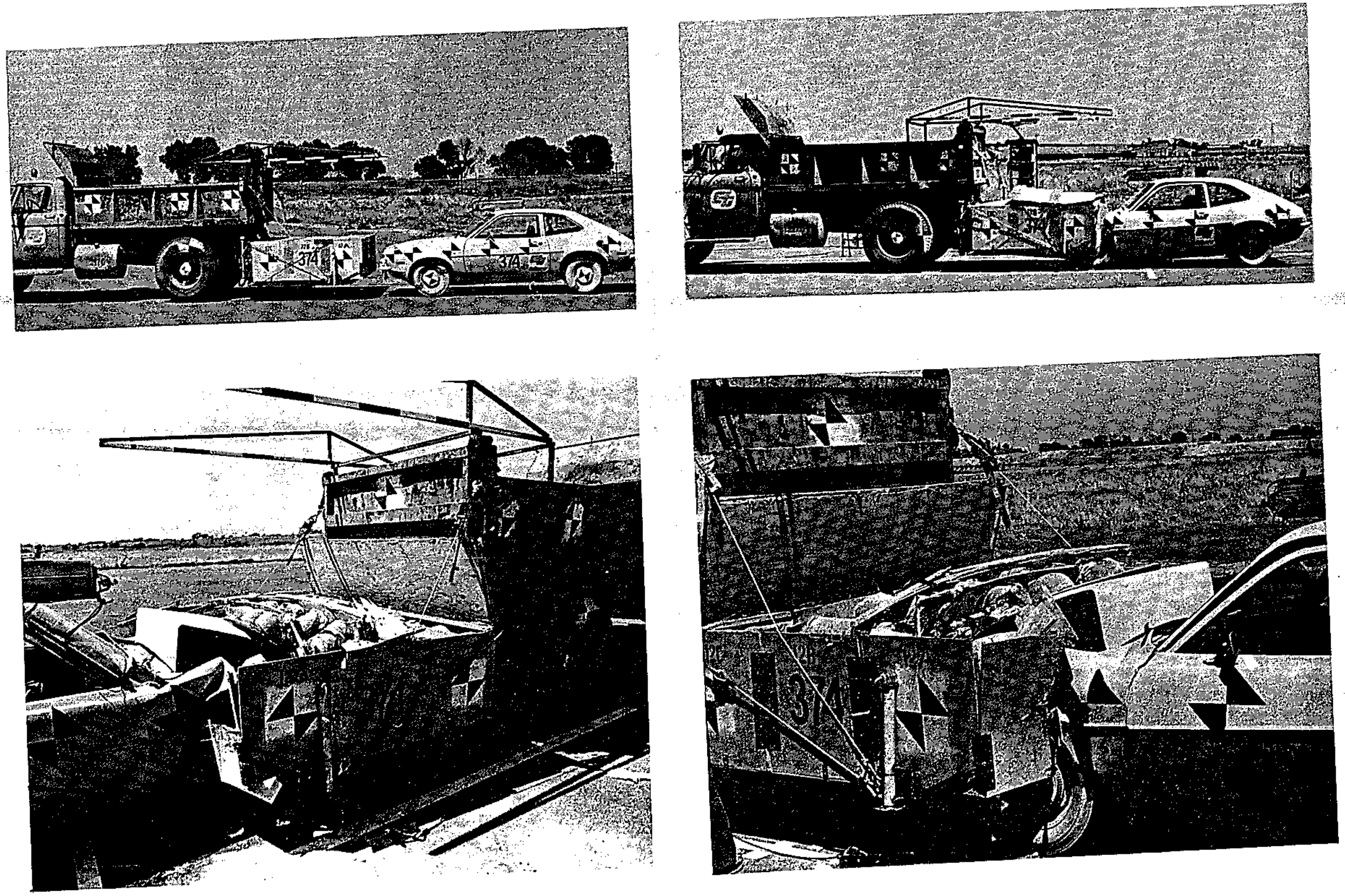
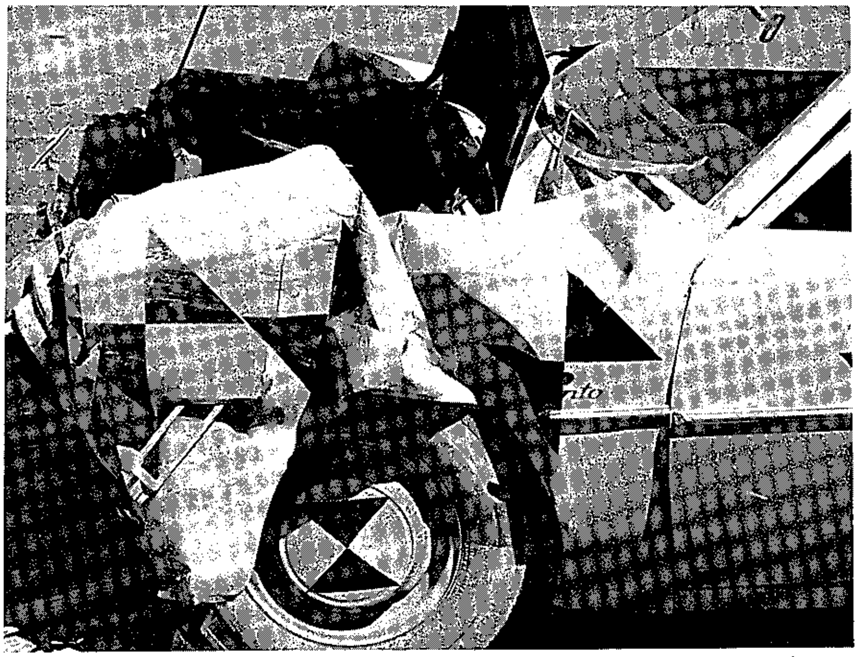


Figure 15. Test 374. Test Vehicles and TMA Before and After Impact

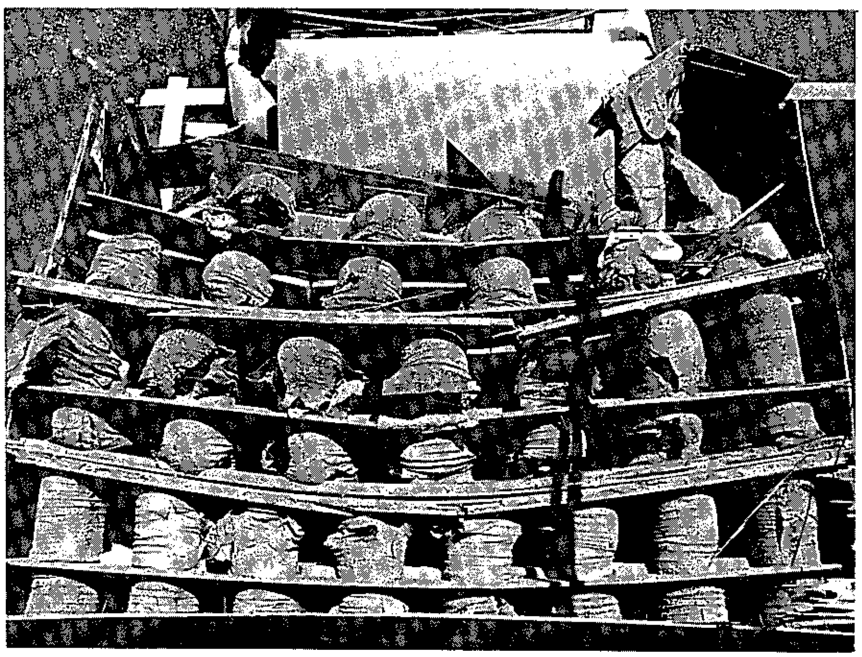
Figure 16.

Test 374

Test Car and TMA After Impact



Test Car Damage



Plan View of TMA With Plywood Cover Removed Showing Crushed Vermiculite Concrete Cells appeared that the car wheels were too small to climb up over this framework so the car could continue crushing the back rows of cells in the TMA.

The dump body of the truck rose 1.1 inches after the truck began moving. There was virtually no yawing or rolling of the car which stayed in contact with the TMA after impact.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -14.0 G's. The comparable value of longitudinal acceleration in the cab of the truck was 2.4 G's.

5.2.4.2 Car Damage - 374

Damage to the car was quite severe. The front end was crushed back a maximum of 22 inches (about 12 inches at the centerline) at a height of 28 inches above ground.

The radiator was crushed and the engine was moved back several inches. The windshield was undamaged but the two doors were jammed, and the roof over the doorposts was crimped. All tires were intact but they were restricted from movement so that the car could not be driven or rolled away. There was no intrusion of vehicle or barrier parts into the passenger compartment.

5.2.4.3 Truck Damage - 374

The only damage to the truck was the broken rear cab window caused by the dummy.

5.2.4.4 TMA Damage - 374

Only part of the energy absorbing capacity of the TMA was used up. The cell-filled box had a permanent maximum crush that varied from 30 inches at the top to 39 inches at the bottom. The steel grid work supporting the box had a permanent maximum crush of 11 inches. The front steel bar of this gridwork had two semi-circular indentations where the car wheels had bent it. There was a small amount of debris from the TMA scattered around the impact area. There was no damage to the TMA controls on the truck or the TMA steel plate backup structure.

5.2.4.5 Dummy Behavior - 374

The dummy in the car struck its chin on the steering wheel which deformed the wheel one inch maximum out of its original plane. The steering column moved down 3/4 inch below the dash. The dash was dented where the dummy's knees struck it.

The back of the head of the dummy in the truck struck the rear window in the cab and broke it. This indicated a possible problem with whiplash for truck drivers when hit from the rear. It should be noted that this occurrence was not necessarily identical to that of an impact with a live driver. See Discussion in Section 5.3.3.

5.2.5 Test EAS-1 Car-2250 lbs/49 mph/0° head-on
Truck 11,740 lbs/all wheels braked/ plus TMA-1400 lbs
(Test conducted by Energy Absorption Systems, Inc. to duplicate Test 374 except that steel grid support under TMA was weakened, Fig. 3. Not financed by this research project.)

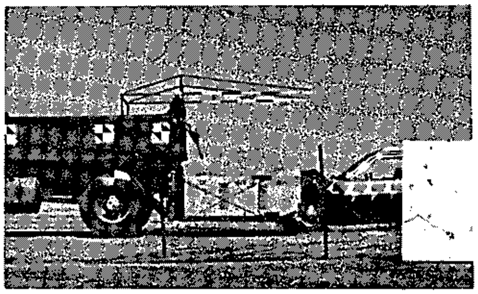
The summary of test data and photos of the vehicles before and after impact are shown in Figures 17 through 19. (Note: The Transportation Laboratory assumes sole responsibility for the accuracy of the data presented. The results are not necessarily all identical to those which may have been obtained by Energy Absorption Systems, Inc.)

5.2.5.1 Impact Description - EAS-1

The car struck the TMA on the truck at the intended angle. The impact speed was 49 mph, higher than the intended speed of 45 mph. The car passed inside the plywood side panels of the TMA and nosed underneath the top plywood panels on the TMA. Car penetration was deep enough that the top panels grazed the windshield of the car. The modified lower grid steel support for the TMA did not appear to restrict forward movement of the car.

There was little truck movement while the car was crushing the TMA. The passenger compartment of the car traveled over six feet after initial impact while the truck traveled a few inches. Beyond this time the car only moved a few more inches, but the truck moved a total distance from its starting point of 3 ft 8 in. The truck wheels had a combination of turning and skidding actions. The EAS report states that loose granular material on their pavement acted similar to ball bearings and caused a stopping distance longer than on clean pavement.

Figure 17. Data Summary Sheet - Test EAS-1



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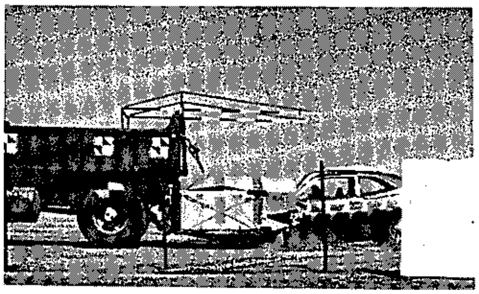

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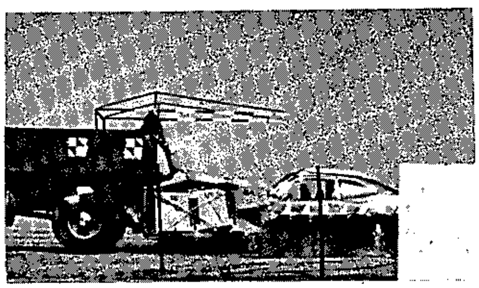

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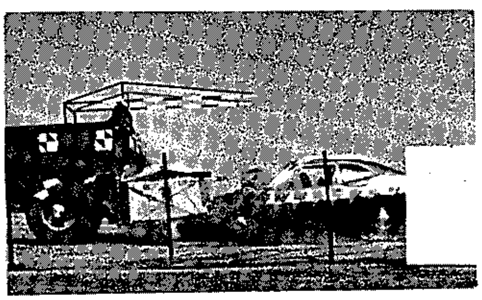
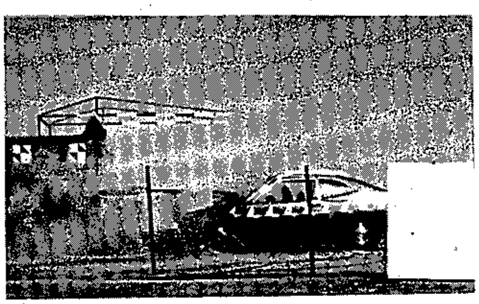


I + 0.50 Sec



I + 1.46 Sec

<u>Test Date</u> September 12, 1979

<u>Truck Mounted Attenuator Data</u>

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1,400 lbs.

<u>Truck Data</u>

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Air, All Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,740 lbs.

<u>Car Data</u>

Model	1972 Ford Pinto Coupe
Impact Velocity	49 mph
Impact Angle	0°
Weight	2,250 lb.
Dummy Type	None Used
Dummy Restraint	N.A.

<u>Impact Data</u>

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	*-12.2g
Truck, Longitudinal	*2.2g
Dummy Head, Resultant	N.A.
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-11.8g
Max. Car Pass.Compart.Decel.Dist.,s	6.8 ft
Truck Roll Ahead Distance	3.7 ft
Max. Pitch, Car	+3.0°
Max. Rise, Truck Dump Body Rear	3.1 in.
TAD/VDI Index, Car	FD-5/12FDEW5

*Reported by Energy Absorption Systems. Caltrans film data showed accelerations of -17.7 and 3.2g's.

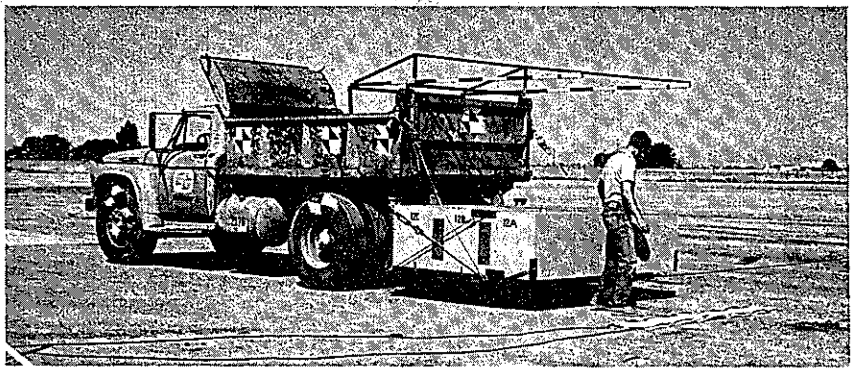
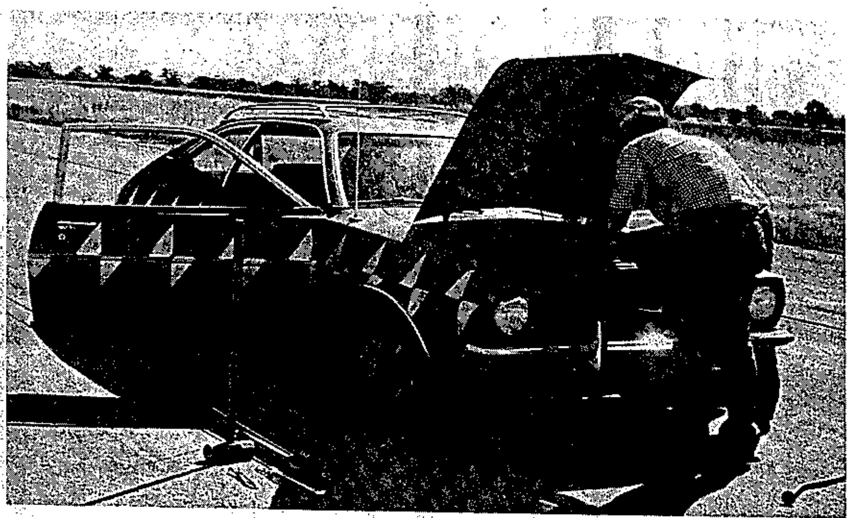
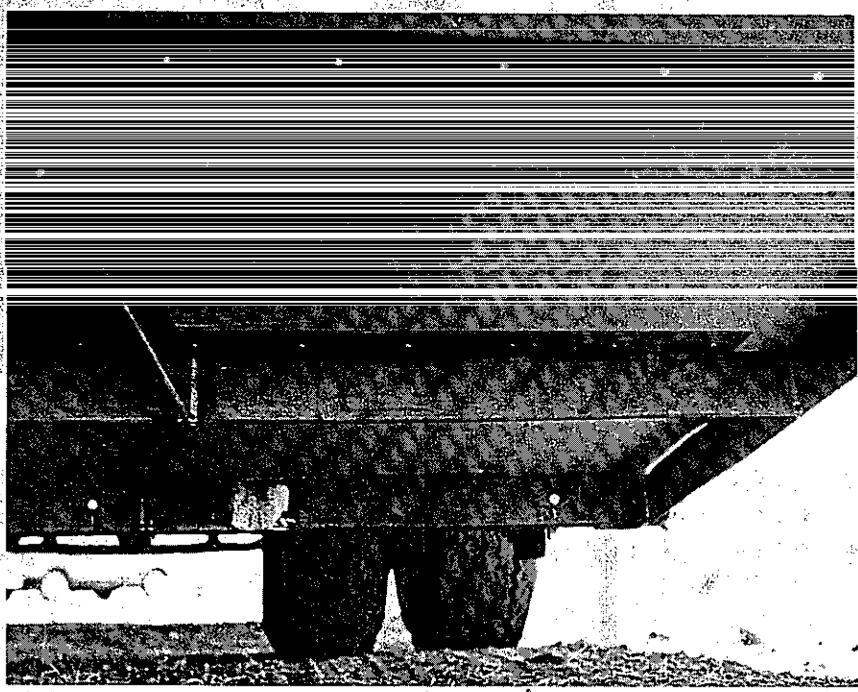


Figure 18.

Test EAS-1

Test Vehicles and TMA Before Impact





Steel Grid Support Beneath TMA Showing Angled Grid Pieces on Left

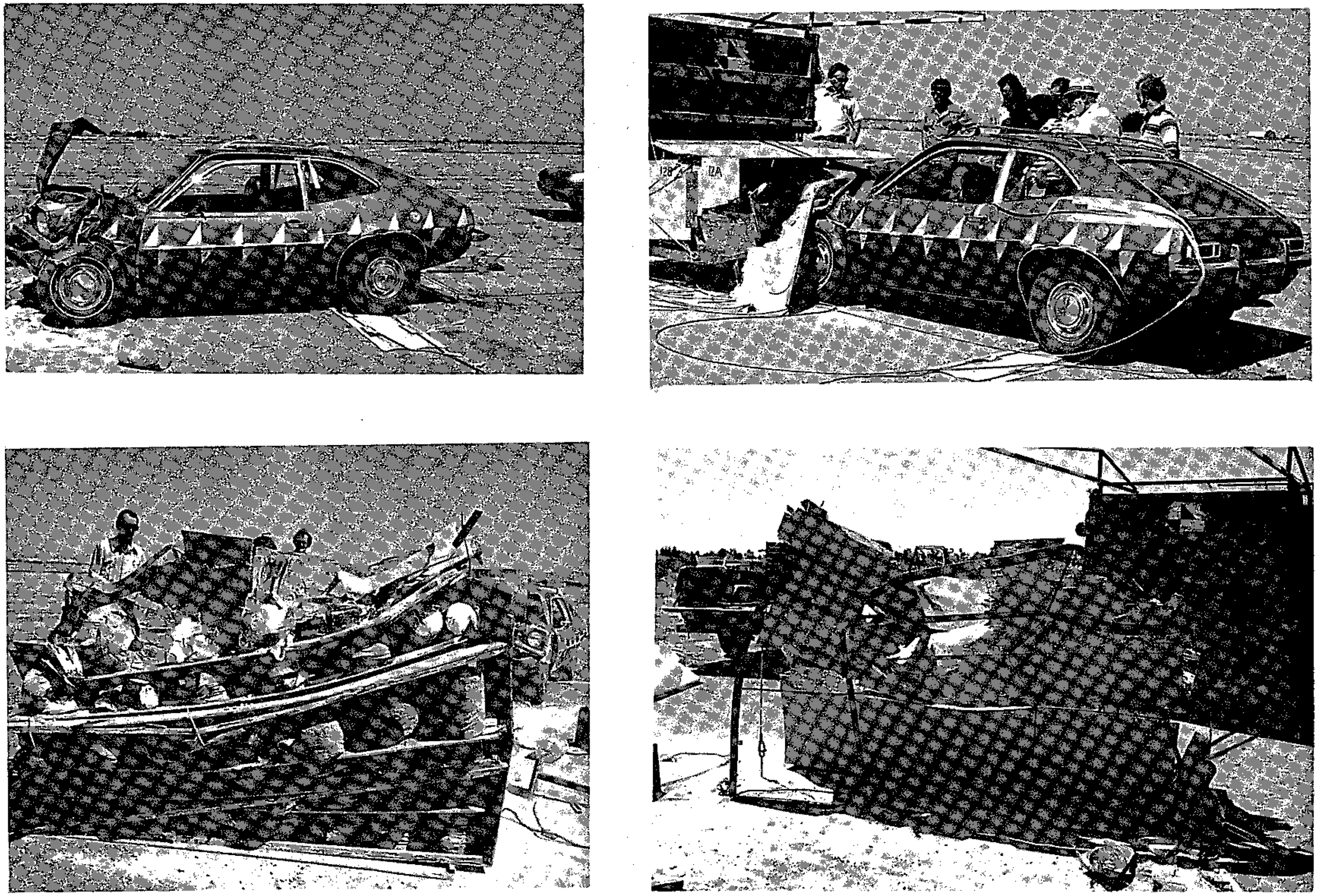


Figure 19. Test EAS-1. Test vehicles and TMA after impact. Bottom photos show top and bottom of TMA which was placed on end.

Other motions of the car and truck were slight. The front end of the car pitched down 3° during impact. The back of the truck dump body rose a maximum of 3.1 inches. There was virtually no yawing or rolling of the car during impact.

Accelerometer records from EAS showed that the maximum 50 millisecond average value of longitudinal acceleration for the car was -12.2 G's. The comparable value of truck acceleration was 2.2 G's. (Accelerometer data was from EAS instrumentation. Values given were from the EAS letter report on the test.)

Caltrans film data yielded a longitudinal 50 ms. average value of acceleration of -17.7 G's. The comparable value of truck acceleration was 3.2 G's.

5.2.5.2 Car Damage - EAS-1

Damage to the car was quite severe. The front end was crushed back a maximum of 24 inches on one side (about 15 inches at the centerline) at a height of 20 inches above ground. The radiator was crushed, and the engine moved back toward the passenger compartment roughly two inches. The windshield was cracked by the hood, the doors were jammed, and the roof over the door posts was crimped. The tires were intact but were restricted from movement so that the car could not be rolled easily away from its resting place. Some plywood pieces were embedded in the crushed front end of the car, but there was no intrusion of vehicle or barrier parts into the passenger compartment of the car. The lower portion of the steering column moved down enough that it pivoted about a support, thus, breaking the dash.

5.2.5.3 Truck Damage - EAS-1

None.

5.2.5.4 TMA Damage - EAS-1

It appeared that all of the energy absorbing length of the TMA was used up. All vermiculite concrete cells were partially or totally crushed. Permanent maximum crush of the cell-filled box was 37-39 inches top and bottom; however, the box components had some rebound after impact. Therefore, maximum dynamic penetration was greater. The steel gridwork supporting the TMA box had a permanent maximum crush of close to 18 inches. As usual there was a small amount of debris from the TMA scattered around the impact area. There was no damage to the TMA controls on the truck or the TMA steel plate backup structure.

5.2.5.5 Dummy Behavior - EAS-1

No dummies were used in the car or truck.

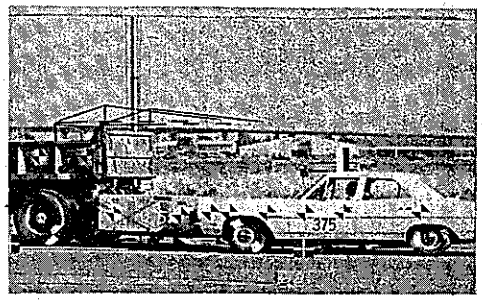
5.2.6 Test 375 Car-4360 lbs/45 mph/15°-3 ft offset
Truck-11,740 lbs/all wheels braked/
plus TMA-1400 lbs

The summary of test data and photos of the vehicles before and after impact are shown in Figures 20 through 22.

5.2.6.1 Impact Description - 375

The car struck the TMA on the truck at the intended speed and angle. The car nosed underneath the top plywood panels on the TMA and crushed the TMA on the left side until it "bottomed out". At that point the right side of the car overlapped the left back side of the truck a little less than 2 ft 0 in. The top panels of the TMA struck the right

Figure 20. Data Summary Sheet - Test 375



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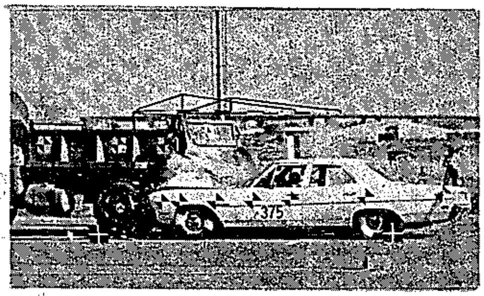
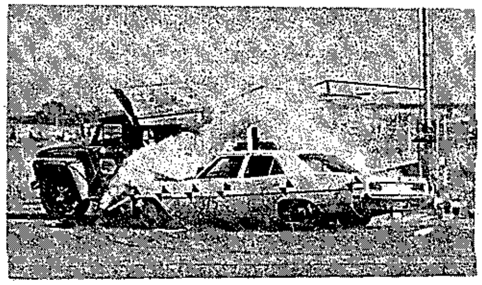


I + 0.15 Sec

I + 0.42 Sec



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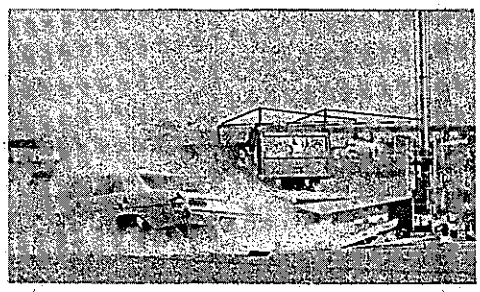


I + 2.05 Sec

Test Date November 1, 1979

Truck Mounted Attenuator Data

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1,400 lbs.

Truck Data

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	F-Air, R-Parking Brakes
Gear Setting	2nd Gear
Weight (w/o TMA)	11,740 lbs.

Car Data

Model	1970 Plymouth Belvedere Sedan
Impact Velocity	45 mph
Impact Angle	3'-0" offset, 15°
Weight	4,360 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

Impact Data

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal/Lateral	-8.8g/-2.5g
Truck, Longitudinal/Lateral	2.5g/1.6g
Dummy Head, Resultant	-11.2g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-2.2g
Max. Car Pass.Compart.Decel.Dist.,s	31.0 ft
Truck Roll Ahead Distance	7.3 ft
Max. Pitch, Car	-1.5°
Max. Rise, Truck Dump Body Rear	7.3 in.
TAD/VDI Index, Car	FR-6/01FREW5

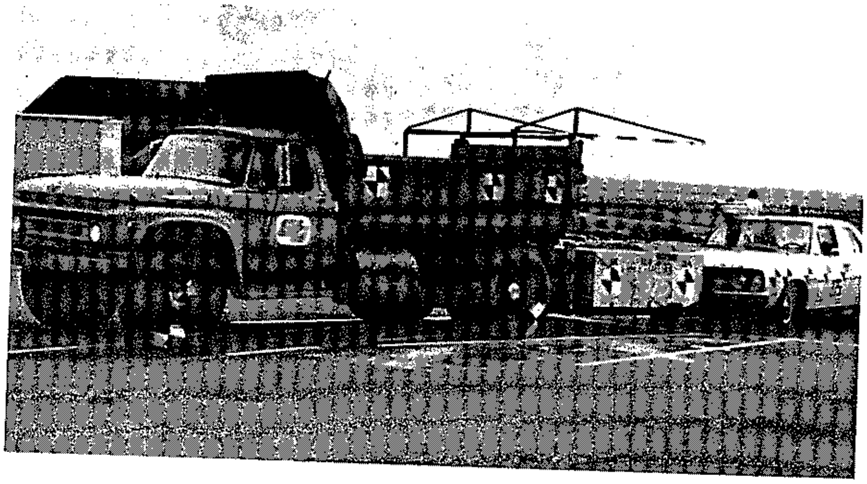
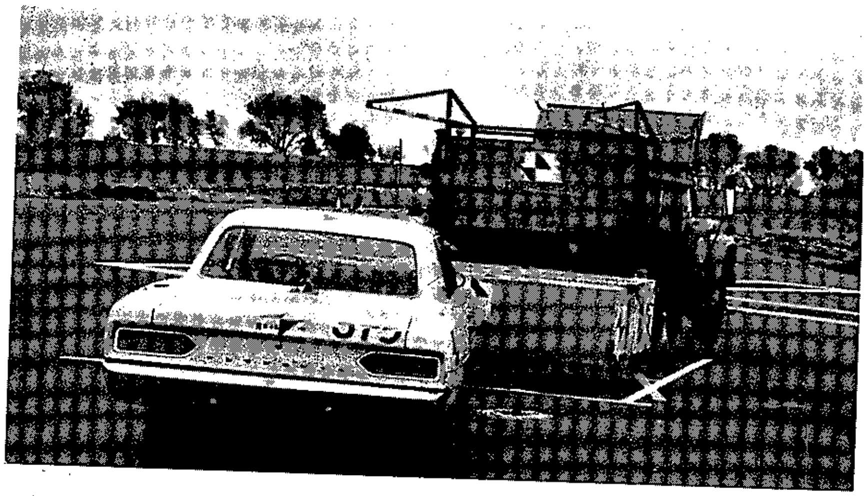
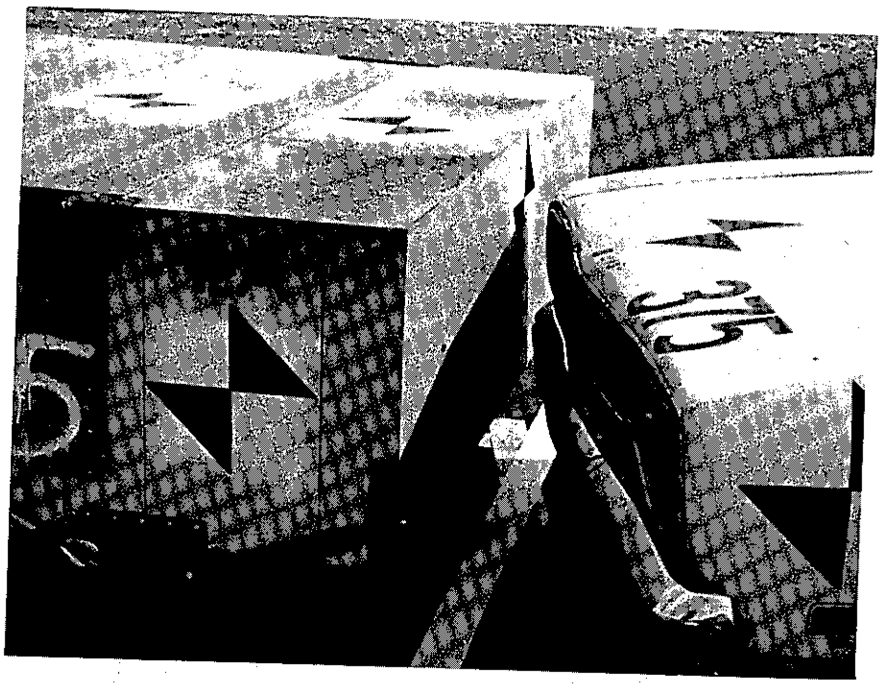


Figure 21.

Test 375

Test vheicles and TMA in position before impact showing 15° angle and 3'-0" offset of car with TMA.





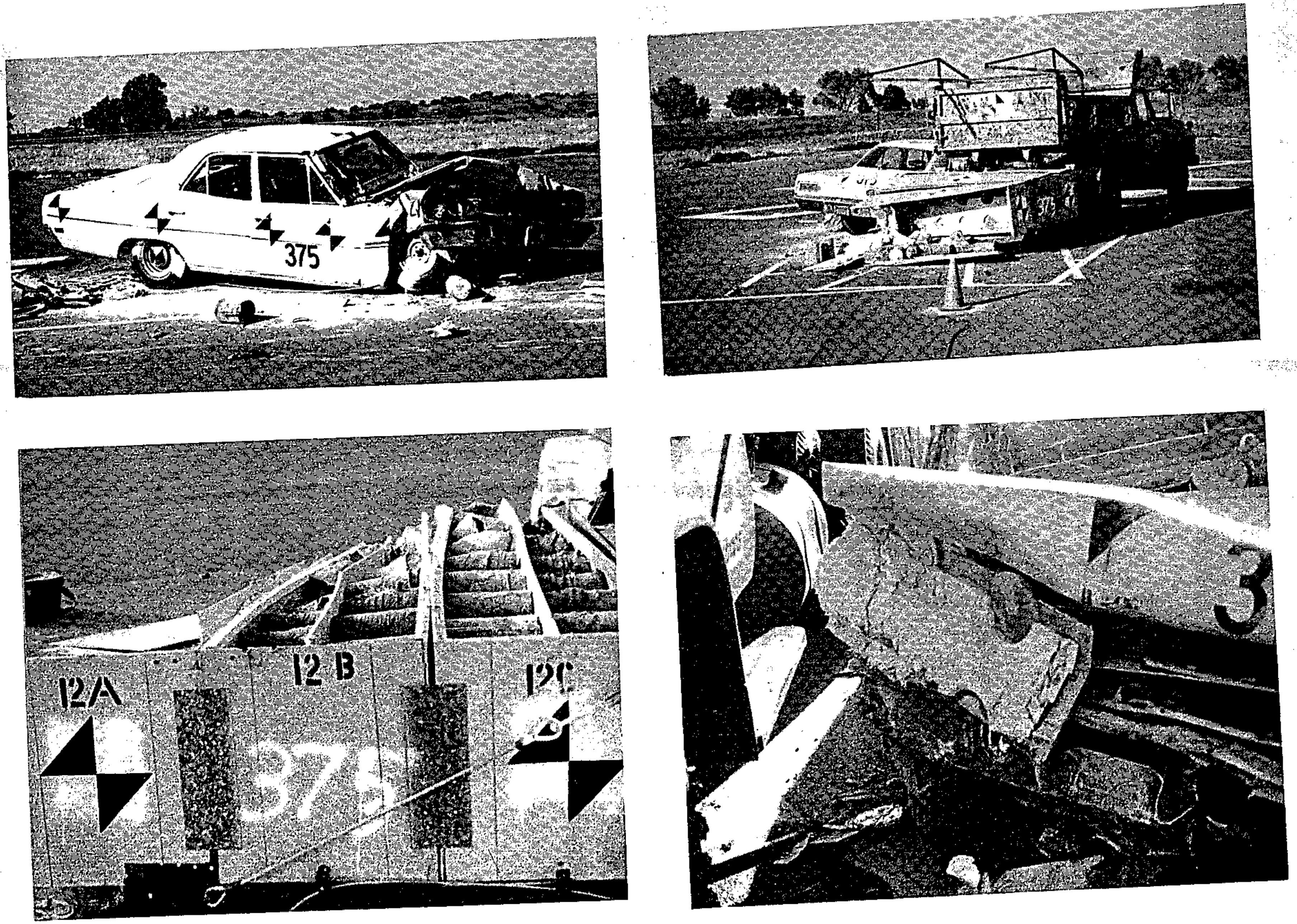


Figure 22. Test 375. Test vehicles and TMA after impact. Lower left: View of crushed cells with plywood cover removed from TMA. Upper and lower right: Final location of car after impact.

frame of the windshield and were forced off to the right side of the car. The car windshield was broken, and the right front corner of the car roof buckled slightly.

There was little truck movement while the car was crushing the TMA. Truck movement was only a few inches ahead by the time the car had first bottomed out after crushing the TMA. Eventually the truck moved ahead 7 ft 3 in. The car yawed clockwise approximately -30°. After the car bottomed out it forced the left rear side of the truck up 7.3 inches, imparting a clockwise roll to the truck of 6.5°. The truck then rolled counterclockwise-7.5°. The car rolled counterclockwise (to the left) about-9°. The entire left side of the car was depressed about six inches during the roll; hence, the pitch of the car was minimal.

The car crushed diagonally back on the right front end which acted like a wedge. Therefore, after the car bottomed out, the wedge-shaped front end forced the car sideways as it continued to move forward. Ultimately the car traveled along the left side of the truck, one to two feet away from it, and stopped a short distance behind the front end of the truck.

During impact the right front wheel of the truck rolled, the right and left rear wheels of the truck skidded most of the distance, and the left front and rear wheels of the car rolled freely. The right front wheel of the car was pinned by the front end crush.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -8.8 G's. The comparable value of longitudinal acceleration in the cab of the truck was 2.5 G's. The values of lateral acceleration for the car and truck respectively were 2.5 G's and 1.6 G's.

5.2.6.2 Car Damage - 375

At a height above ground of 23 inches the car crushed back 34 inches on the right front, almost on a flat diagonal plane, to a value of zero inches of crush on the left front.

The radiator was crushed, the windshield was broken, but the engine did not move rearward. The right front door was jammed, and the roof over the doorposts was crimped. The tires were intact but the front wheels were restricted from movement. The car could not have been driven or rolled away from the impact site.

The right side of the dash and the heater intruded six inches into the passenger compartment; otherwise there was no intrusion of vehicle parts.

5.2.6.3 Truck Damage - 375

None.

5.2.6.4 TMA Damage - 375

Only the left side of the TMA was fully crushed back. However, the right side had some crushing in all rows of cells through the back row. This indicates that the inner plywood diaphragms of the TMA were stiff enough to distribute some of the impact load across the entire width of the TMA. Maximum permanent crush of the TMA varied from 34 inches on the left to nothing on the right. The steel undercarriage of the TMA had a maximum crush of 30 inches. The steel plate backup structure for the TMA was bent slightly on the left side due to the offset impact.

5.2.6.5 Dummy Behavior - 375

The dummy was effectively restrained by its lap and shoulder belts. It moved forward into the shoulder belt during the TMA crushing stage, then moved right toward the passenger seat as the car skidded to the left after it had bottomed out. There was no apparent damage to the steering wheel, dash, or windshield like that in some previous tests due to dummy impacts.

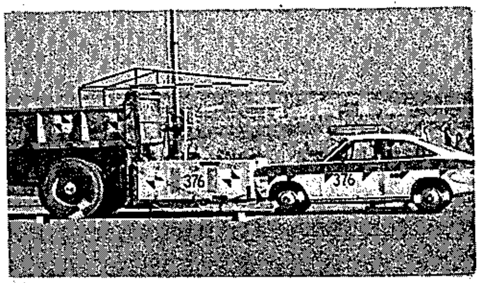
5.2.7 Test 376 Car-1890 lbs/44 mph/0° head-on Truck-11,740 lbs/rear wheels braked/ plus TMA-1400 lbs

The summary of test data and photos of the vehicles before and after impact are shown in Figures 23 through 26.

5.2.7.1 Impact Description - 376

The car struck the TMA on the truck at the intended speed and angle. The car passed inside the plywood side panels of the TMA and nosed underneath the top plywood panels on the TMA. The top panel hit the windshield of the car as it bottomed out, but the truck then rolled ahead so that the top panels lost contact with the windshield.

Figure 23. Data Summary Sheet - Test 376



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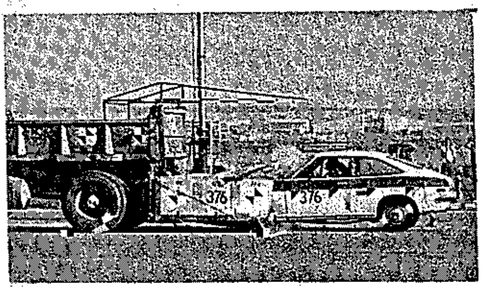

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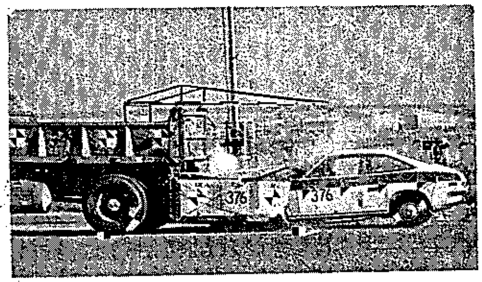

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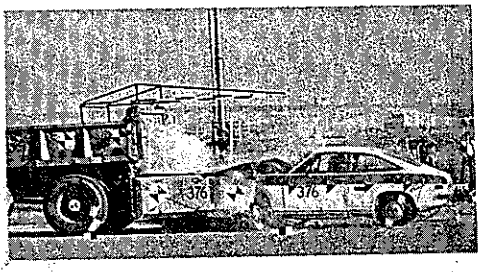
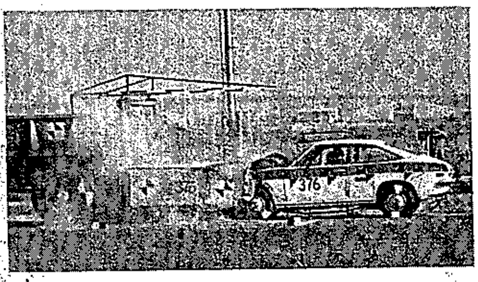


I + 0.42 Sec



I + 1.70 Sec

Test Date December 6, 1979

Truck Mounted Attenuator Data

Type	ABC, Vermiculite Concrete Cells
Size	6' long x 8' wide x 2' high
Weight	1400 lbs.

Truck Data

Model	Ford F750 Dumptruck
Gross Veh. Wt.	Rated 25,000 lb.
Dump Body Capacity	4 cu. yds.
Brake Setting	Parking Br., Rear Wheels
Gear Setting	2nd Gear
Weight (w/o TMA)	11,740 lb.

Car Data

Model	1972 Datsun 1200 Coupe
Impact Velocity	44 mph
Impact Angle	0°
Weight	1,890 lbs.
Dummy Type	Part 572, 50th Percentile
Dummy Restraint	Lap, Shoulder Belts

Impact Data

Max. 50ms. Avg. Acceleration, Accelerometers	
Car, Longitudinal	-17.9g
Truck, Longitudinal	2.8g
Dummy Head, Resultant	-36.1g
Avg. Acceleration ($V^2/2gs$)	
Car, Passenger Compartment	-12.4g
Max. Car Pass.Compart.Decel.Dist.,s	5.2 ft
Truck Roll Ahead Distance	3.2 ft
Max. Pitch, Car	+1.0°
Max. Rise, Truck Dump Body Rear	2.6 in.
TAD/VDI Index, Car	FD-5/12FDEW5

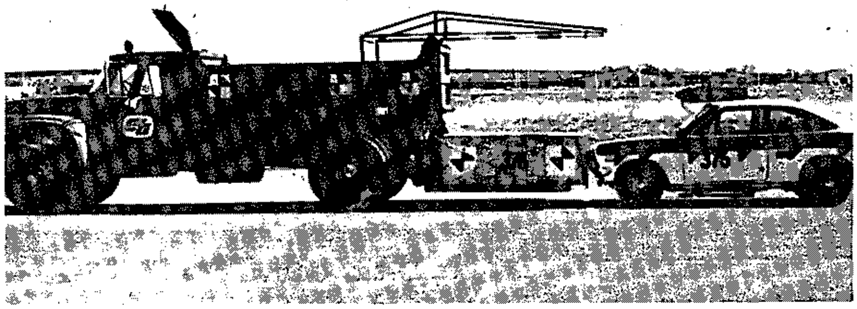
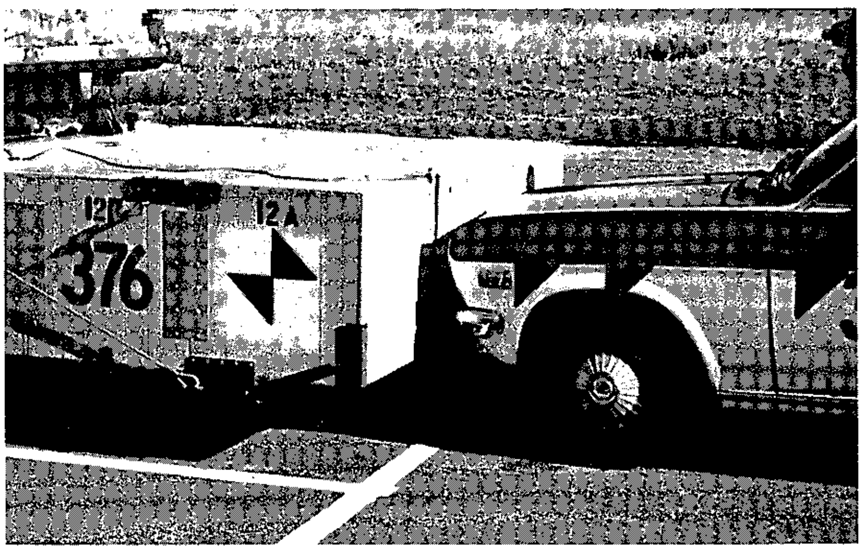
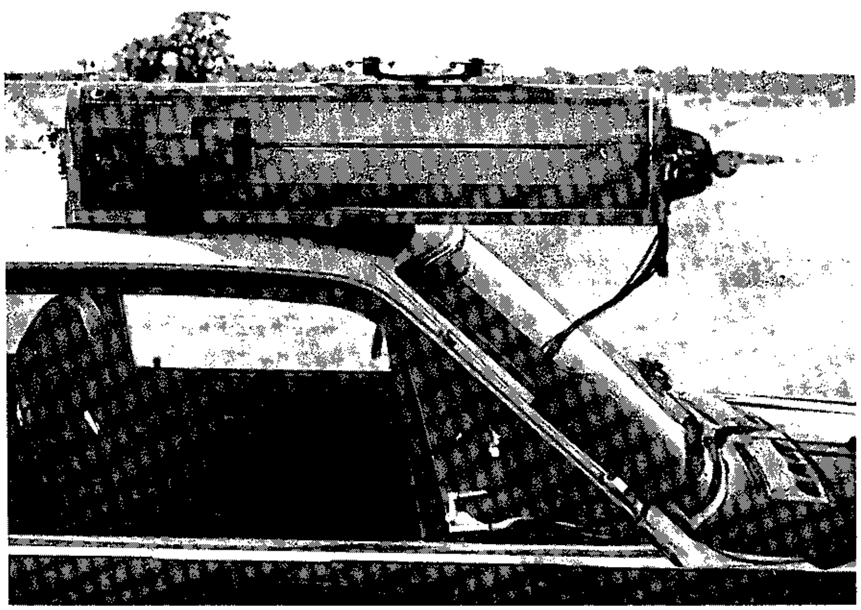


Figure 24.

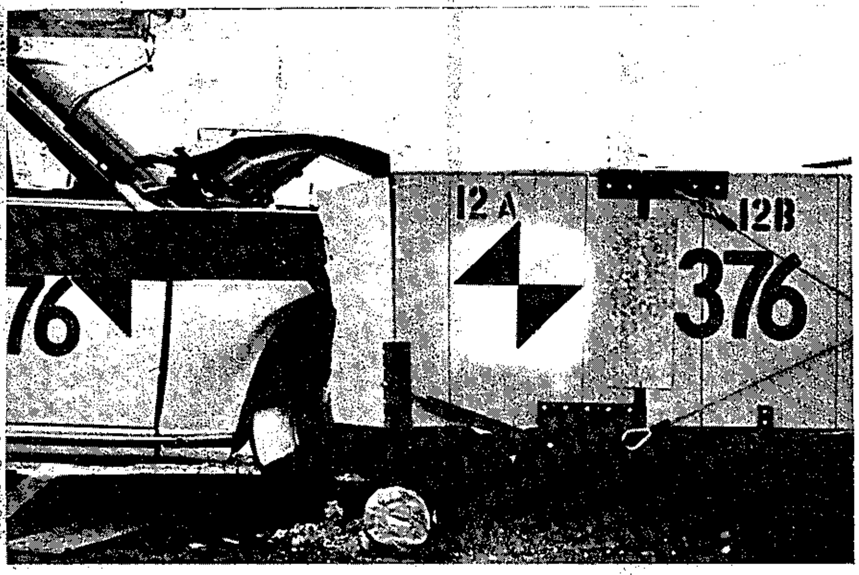
Test 376

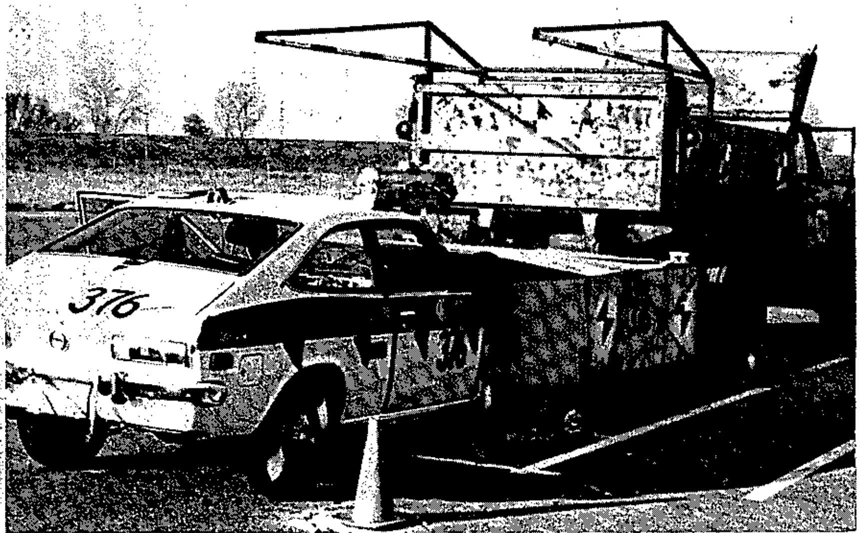
Test vehicles & TMA in position before impact.





Sliding weight device used to determine change of momentum.





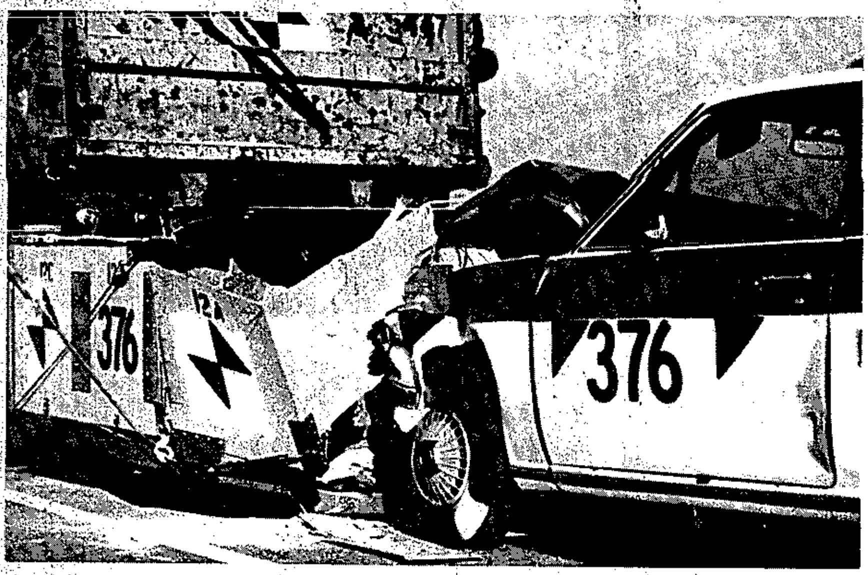
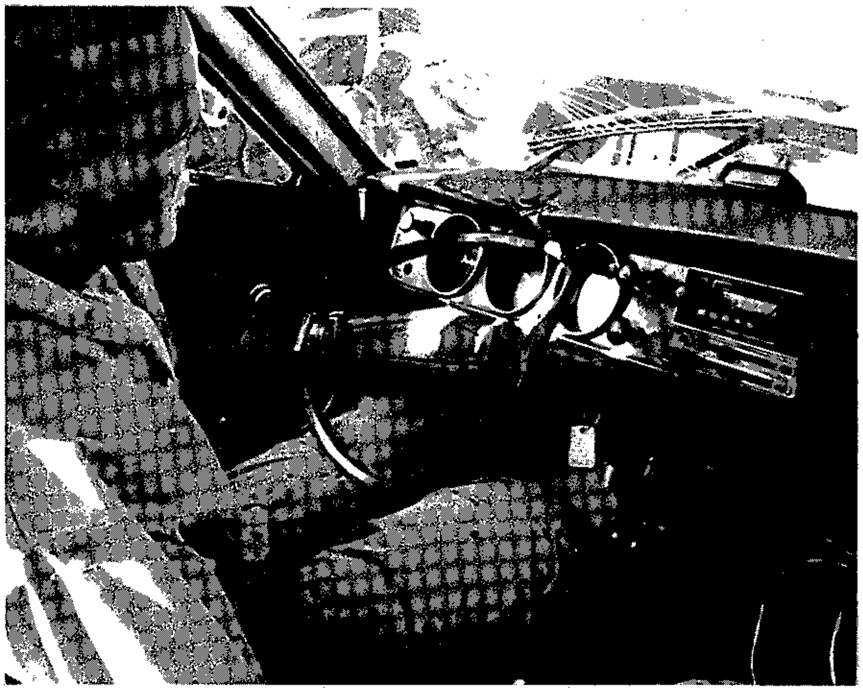


Figure 25.

Test 376

Test car, truck & TMA after impact.

Car wheels did not rise above steel grid support on bottom of TMA.



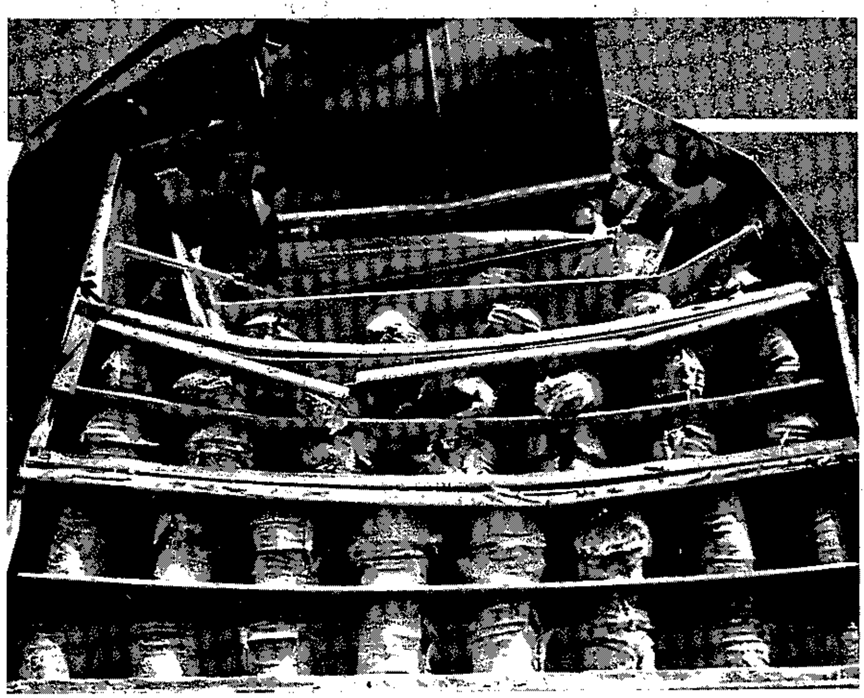


Figure 26. Test 376, Post-Impact.

Upper: Damage to winshield, dash, & steering wheel.

Lower: Plan view of crushed TMA with plywood cover removed.

There was little truck movement while the car was crushing the TMA. The car attained maximum penetration into the TMA before the truck had traveled more than a few inches. Ultimately the truck moved ahead 3 ft 2 in. While the truck moved ahead, the left rear wheel skidded and also turned 69°. The left front wheel turned freely because it wasn't braked. Pitch of the car during impact was minimal, no more than 1° up and down. The car had virtually no roll or yaw movements during impact. The rear end of the truck initially was forced down about two inches as the car forced down the bottom TMA frame; then the truck sprang up 2.6 inches. The rearmost bar on the bottom frame of the TMA had obvious indentations where the front wheels of the car had tried to push through it. This frame was the modified design used in Test 375 and the Energy Absorption Systems' test (EAS-1). The car wheels never rode up on top of the frame.

The maximum 50 millisecond average value of longitudinal acceleration for the passenger compartment of the car was -17.9 G's. The comparable value of longitudinal acceleration in the cab of the truck was 2.8 G's.

It was intended that the air brakes be actuated to lock all the truck wheels when the car struck a tape switch mounted at the rear of the truck-mounted attenuator (TMA). However, this brake device did not function and the air brakes were never on. Thus only the rear brakes were set during this impact.

5.2.7.2 Car Damage - 376

At a height above ground of 24 inches, the front of the car was crushed back approximately 10 1/2 inches. The front frame members were bent, and the radiator was crushed back beyond the fan. The windshield was cracked. The tires were intact, but restricted from movement so the car could not be driven or rolled away from the impact area. There was no intrusion of vehicle or barrier parts into the passenger compartment.

5.2.7.3 Truck Damage - 376

None.

5.2.7.4 TMA Damage - 376

Only part of the energy absorbing capacity of the TMA was used up. The cell-filled box had a permanent maximum crush of 24 inches. The steel gridwork beneath the box had a permanent maximum crush of about 18 inches. The small amount of debris scattered close to the impact area was typical of previous tests. There was no damage to the TMA controls on the truck or the TMA steel plate backup structure.

5.2.7.5 Dummy Behavior - 376

The dummy was restrained with a lap belt but no shoulder belt, which allowed the upper body of the dummy to crash into the front interior surfaces of the passenger compartment and crack the windshield. The seat back and head restraint followed the dummy closely and slammed into its back. The steering column collapsed about four inches to the thigh area of the dummy, and the steering wheel was broken top and bottom and deformed about five inches away from the original plane. The dummy's head slammed into the windshield and the dash and crushed the dash around the area of impact. The shoulder belt was not used because there was no connecting strap or anchor available on the right side of the driver's seat.

5.3 Discussion of Test Results

5.3.1 General - Criteria

In TRC No. 191, (1) three appraisal factors are recommended for use in judging performance of highway safety appurtenances. These factors can be applied to the results of the TMA tests, although TMA's are not specifically mentioned in this reference. The three factors, which will be discussed below, are (1) structural adequacy, (2) impact severity, and (3) vehicle trajectory.

Tables 1 and 2 summarize the data from all seven tests including the EAS test. The test results are also compared with those of the first four tests on the Connecticut TMA which are thoroughly documented in Reference 4.

The film report on this project can be used to compare the six tests conducted by Caltrans.

5.3.2 Structural Adequacy - Vehicle and TMA Damage

In Table 4 of TRC No. 191 (1) this appraisal factor is described as follows for crash cushions in general:

> "B. The test article shall not pocket or snag the vehicle causing abrupt deceleration or spinout or shall not cause the vehicle to rollover. The vehicle shall remain upright during and after impact although moderate roll and pitching is acceptable. The integrity of passenger compartment must be maintained. There shall be no loose elements, fragments, or other debris that could penetrate the passenger compartment or present undue hazard to other traffic."
>
> "C. Acceptable test article performance may be by redirection, containment, or controlled penetration by the vehicle.

TABLE 1 - SUMMARY OF TEST RESULTS: VEHICLE KINEMATICS

	NO TMA	HEAVY CARS			LIGHT CARS			ANGLE, OFFSET			MINI-
Test No.	371	372	373	2	374	EAS-1	1	375	3	4	376
TMA Type	None	Verm	Verm	Pipe	Verm	Verm	Pipe	Verm	Pipe	Pipe	Verm
Testing Agency	Calif	Calif	Calif	Conn	Calif	EAS	Conn	Calif	Conn	Conn	Calif
Car Weight, lbs.	4480	4400	4420	4480	2140	2250	2260	4360	4480	4470	1890
Speed, mph	45	45	45	46.5	45	49	45.8	45	45.5	45.8	44
Angle, degrees	0	0	0	0	0	0	0	15	0	10	0
Offset, ft.	0	0	0	0	0	0	0	3.0	2.5	2.5	0
Truck & TMA Wt., lbs.	11600	13140	13140	16000	13300	13140	15980	13140	16000	16000	13140
Brake Setting	All	All	Rear	Off	All	All	Off	All	Off	Off	Rear
Gear Setting	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
Car at Impact: Momentum(M) (k-sec)	9.18	9.02	9.06	9.49	4.39	5.02	4.71	8.93	9.28	9.32	3.79
Kin.Energy(K)(ft-k)	303	298	299	331	145	181	159	295	310	314	122
Roll Ahead (ft) C = Car	13.9	13.9	18.0	8.5	6.1	6.8	7.1	31.0	8.8	8.9	5.2
T = Truck	10.3	7.9	13.8	18.6	2.4	3.7	8.3	7.3	16.2	14.8	3.2
Average Crush, Front of Car (in.)	26.5	12.2	6.3	11.5	10.9	13.7	11.0	L-0,Rt-34	Rt 2/3 -22.5	L-0,Rt-32	10.2
Max. Angle Change of Car *Pitch (P) (deg)	-8.0	-10.0	-7.8	No data	+3.5	+3.0	No data	-1.5	No data	No data	+1.0
Yaw (Y) (deg)	0	+2.0	0	0	0	0	0	-30	-12	-40	+1.0

*Pitch scale, 0-16°, used for positive and negative values

TABLE 2 - SUMMARY OF TEST RESULTS: DECELERATION DATA

	NO TMA	HEAVY CARS			LIGHT CARS			ANGLE, OFFSET			MINI-
Test No.	371	372	373	2	374	EAS-1	1	375	3	4	376
TMA Type	None	Verm	Verm	Pipe	Verm	Verm	Pipe	Verm	Pipe	Pipe	Verm
Testing Agency	Calif	Calif	Calif	Conn	Calif	EAS	Conn	Calif	Conn	Conn	Calif
Car Weight, lbs.	4480	4400	4420	4480	2140	2250	2260	4360	4480	4470	1890
Speed, mph	45	45	45	46.5	45	49	45.8	45	45.5	45.8	44
Angle, degrees	0	0	0	0	0	0	0	15	0	10	0
Offset, ft.	0	0	0	0	0	0	0	3.0	2.5	2.5	0
Truck & TMA Wt., lbs.	11600	13140	13140	16000	13300	13140	15980	13140	16000	16000	13140
Brake Setting	All	All	Rear	Off	All	All	Off	All	Off	Off	Rear
Gear Setting	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd	2nd
Car at Impact: Momemtum(M) (k-sec)	9.18	9.02	9.06	9.49	4.39	5.02	4.71	8.93	9.28	9.32	3.79
Kin.Energy(K)(ft-k)	303	298	299	331	145	181	159	295	310	314	122
Max. 50 ms. Avg. Long. Accel. (g) (Accelerometers) C = Car	-21.5	-9.7	-10.8	-14.9	-14.0	-12.2*	-13.5	-8.8	-11.0	-10.4	-17.9
T = Truck	+5.0	+3.5	+4.3	+4.7	+2.4	+2.2*	+0.4	+2.5	+4.2	+3.4	+2.8
Avg. Long. Accel. Car Pass. Comp. F = Veloc. Curve Slope (Film)	-18.5	-9.6	-10.0	No data	-15.5	-17.7	No data	-8.5	No data	No data	-19.4
a = $V^2/2gs$	-4.9	-4.9	-3.8	-8.5	-11.1	-11.8	-9.8	-2.2	-7.7	-7.8	-12.4
Max. 50 ms. Avg. Resultant Acceleration in Dummy's Head (g)	-39.2	-21.5	-18.4	No data	-28.3	No data	No data	-11.2	No data	No data	-36.1

*Data from Energy Absorption Systems, Inc.

5.3.2.1 Integrity of Car Passenger Compartment and Damage to Car

There was no intrusion of vehicle or barrier parts into the passenger compartment in Tests 372-374 and 376 when the TMA was used. In Test 375, the angle impact test, there was some intrusion on the right front side of the passenger compartment. In Test 371 there was no TMA on the truck and the dashboard and steering column of the car were pushed a short distance into the passenger compartment. In addition, the hood barely punched through the windshield and there was some buckling of the floorboard. In all tests the top plywood panel of the TMA remained above the car hood and made contact with the car windshield. Although the windshield cracked in some tests, it did not appear to be a threat to passengers. If the impact speeds had been over 45 mph, however, this top panel might have been more hazardous. Although there was no damage to the dummy in Test 371, the other tests clearly showed there was better protection of the passenger compartment with a TMA mounted on the truck. This difference probably would be even more evident at impact speeds over 45 mph.

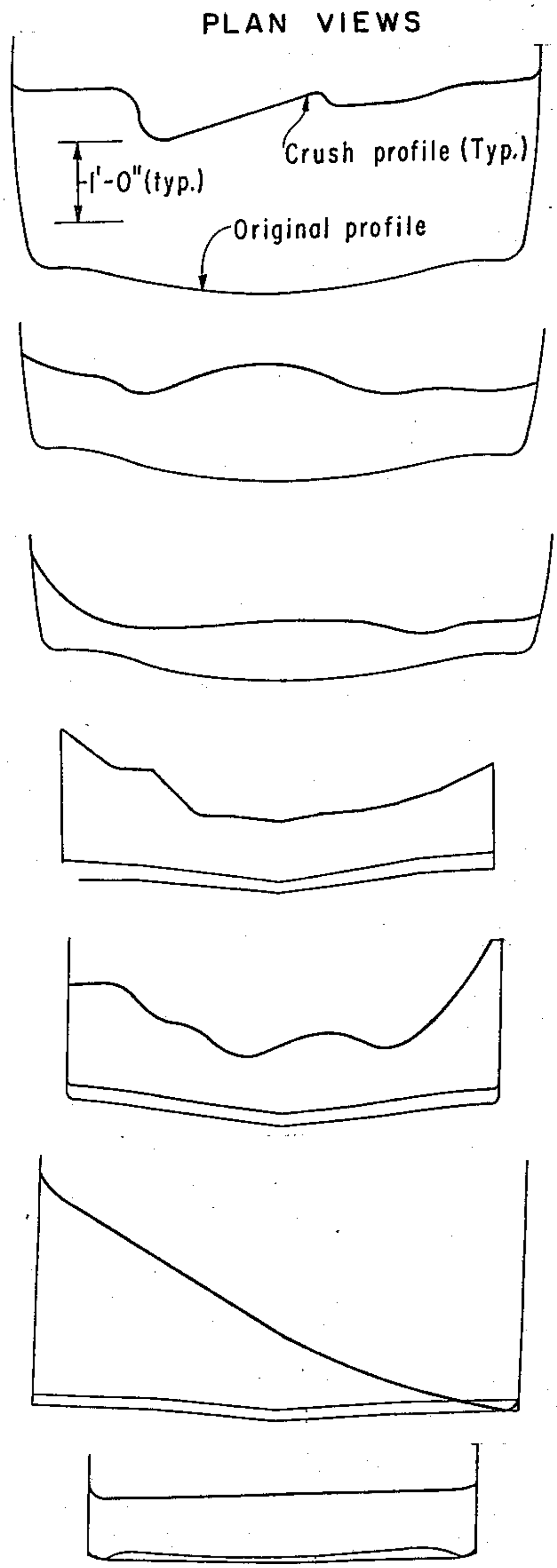
One measure of car damage is the amount of crush to the front end. It is difficult to compare the vehicle crush in different tests because different model cars were used with different front end components, each having different crush resistances. Even when same model cars were used, slight differences in the vehicle kinematics could affect the final crush profile. The method used to compare crush was picked arbitrarily. Using a plan view of the car showing the original and the final crushed profile, the total crush area was measured and divided by the car width to obtain an average value of crush. The values for all tests are shown in Table 1. The crush profiles are shown in Figure 27. The California and Connecticut values were all quite similar, between 10.2 and 12.2 inches, for the headon tests at 45 mph except for Test 371. In Test 371 where no TMA was used, the crush was 26.5 inches which shows dramatically the usefulness of the TMA. In Test EAS-1 the crush was 13.7 inches which may be due to the higher impact speed of 49 mph with a consequent increase in kinetic energy that is proportional to the square of the velocity. Although the crush values were similar in the 45 mph/headon impacts for both large and small cars, that value of crush in a small car represents a more severe impact than for a large car as is evidenced by the larger values of deceleration, Table 2. The car crush profiles for Test 375 and Connecticut Test 4 were almost identical; zero crush on one side and 34 and 32 inches respectively on the other. The crush in Test 373 was only half that in Test 372. This is probably due to the unbraked front truck wheels in Test 373 which allowed the truck to move without so much force buildup at the front of the car.

The VDI (10) and TAD (11) car damage scales are given on the Data Summary Sheets for each test. They also show that the amount of car damage was similar for all tests except Test 371 where damage was much more severe.

5.3.2.2 Damage to TMA and Truck

In Tests 372 and 373 with the large cars, virtually all cells in the TMA were totally crushed. In Tests 374 and 376 with the smaller cars, some of the back rows of cells

Figure 27, TEST CAR - FRONT END CRUSH PROFILE



Test 371

1971 AMC Matador
Crush profile measured @ 24" above ground
Avg. crush = 26.5"

Test 372

1971 AMC Matador
Profile @ 24"
Avg. crush = 12.2"

Test 373

1971 AMC Matador
Profile @ 24"
Avg. crush = 6.3"

Test 374

1972 Ford Pinto
Profile @ 28"
Avg. crush = 10.9"

Test EAS-1

1972 Ford Pinto
Profile @ 20"
Avg. crush = 13.7"

Test 375

1970 Plymouth Belvedere
Profile @ 23"
Max. crush = 34"

Test 376

1972 Datsun 1200
Profile @ 24"
Avg. crush = 10.2"

were not crushed or were only slightly crushed. Hence, the tests show that the TMA was designed close to the ideal stiffness for large cars at 45 mph because all the crush distance available in the TMA was used up, and the deceleration was under the 12 G maximum allowable. The TMA design was not ideal, however, for small cars because not all crush distance was used and consequently the decelerations were excessive. Softer cell and/or less cells would be necessary to maximize the TMA performance for small cars. In order to maximize performance for both large and small cars, the TMA would have to be increased in length, and fitted with less and/or softer cells at the back section of the TMA to accommodate small cars.

In Test EAS-1 with a small car most of the cells were crushed. This appears to belie the above conclusions; however, the test speed was 49 mph which combined with a slight difference in weight increased the kinetic energy by 25% over that of the same size car in Test 374. The deceleration was excessive in Test EAS-1 which confirms that the cell layout was too stiff for that size car. Penetration of the car in EAS-1 also may have been increased over that in Test 374 partly because the steel grid support under the TMA was made more flexible. Maximum crush of that frame went from 11 inches in Test 374 to 18 inches in Test EAS-1. In both tests the front wheels of the car were ultimately resisted by that frame whereas the larger wheels of the cars in Tests 372 and 373 rode over the top of the frame. Data from the test movies show the maximum dynamic penetration of the cars during impact. The penetration represents the dynamic crush of the TMA and car front end:

Test No.	Maximum Dynamic Penetration of Car
371	4.8 ft
372	7.3
373	6.1
374	5.1
EAS-1	6.0
375	N/A
376	4.4

Most of this penetration occurred before the truck had moved ahead more than a few inches.

Penetration in Test 371 was relatively less, of course, because there was no TMA. The penetration includes the distance the car nosed under the truck and the crush of the car.

Penetration in Test 373 was slightly less than in Test 372. This may be explained by the fact that the truck front wheels were not braked in Test 373. When the car pushed up on the rear of the truck during impact, the truck rear wheel braking was not fully effective and the truck rolled ahead more easily.

In all tests with the TMA there was no damage to the TMA steel backup frame and controls with the following exceptions. There was light damage in Test 372 and the frame bent a fraction of an inch in Test 375.

A small steel brace was added to the truck after Test 372 at a TMA mounting location which was helpful in further tests.

The truck had some rear end damage in Test 371 without a TMA, but there was no truck damage in the remaining tests when TMA's were used except for the one brake actuator damaged in Test 372. Hence, for the test conditions of this study, the truck was shielded effectively by the TMA.

Debris from the TMA was confined to a fine layer of powder from the crushed cells deposited close to the truck and car, small pieces of splintered plywood from the TMA enclosure also landing close to the car and truck, and a number of screws from the TMA box splice plates.

The debris generally would not pose a hazard to nearby traffic - either real or psycholoical. In a severe impact the screws possibly could scatter and cause tire damage.

5.3.2.3 Car and Truck Kinematics

There was no loss of control or stability to the truck or car during the tests. The pitch, roll and yaw of the car were minimal. Values of pitch and yaw are given in Table 1. The TMA controlled the deceleration of the car in all tests even though it was not always optimal. Even in Test 375, the offset angular impact, where it was surmised the car might spinout, instead it slithered around the left side of the truck and stopped close beside it.

5.3.3 Impact Severity: TMA Cushioning Effectiveness

The guidelines for highway crash cushions in Table 4 of TRC No. 191 (1) are as follows:

> "C. For direct-on impacts of test article, where vehicle is decelerated to a stop and where lateral accelerations are minimum, the preferred maximum vehicle acceleration average is 6 to 8 g's and the maximum average permissible vehicle deceleration is 12 g as calculated from vehicle impact speed and passenger compartment stopping distance."

These criteria will be used to evaluate the TMA. It should be noted, however, that the above standard was intended for 60 mph impacts. In this series the impact speeds were 45 mph because of the 6 ft 0 in. length limit on the TMA.

5.3.3.1 Car Deceleration

The deceleration was computed in three ways and is tabulated in Table 2. 1) The 50 ms average value from accelerometer data is considered the most accurate because it is a direct measurement. The accelerometer records are contained in Appendix C. 2) Displacement data for the car was taken from the test movies and used to compute and plot velocity curves shown in Figures 28-34. The maximum slope (the acceleration) over a 50 ms period was taken from the velocity curves. These values were generally within about one g of the accelerometer values. The exception was Test 371, but both methods gave high values of -18.5 and -21.6 g's that were well above the tolerable limits,

Figure 28, Velocity vs Time, Vehicles in Test 371

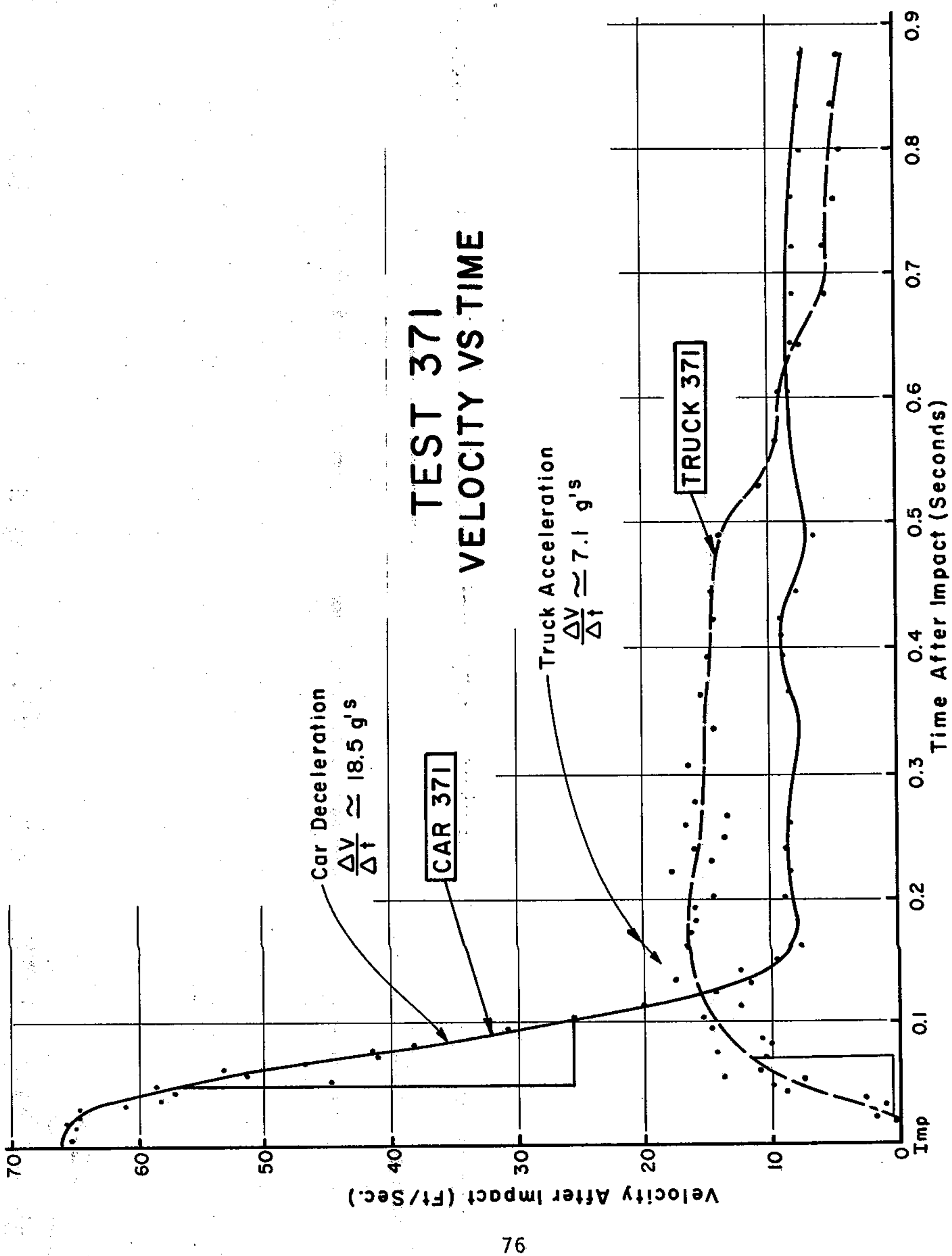


Figure 29, Velocity vs Time, Vehicles in Tests 371, 372, & 374

Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
371	4480	-18.5	.05 - .10	+7.1	.02 - .07	-21.5
372	4400	- 9.6	.06 - .11	+5.8	.15 - .20	- 9.7
374	2140	-15.5	.07 - .12	+2.1	.09 - .14	-14.0

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

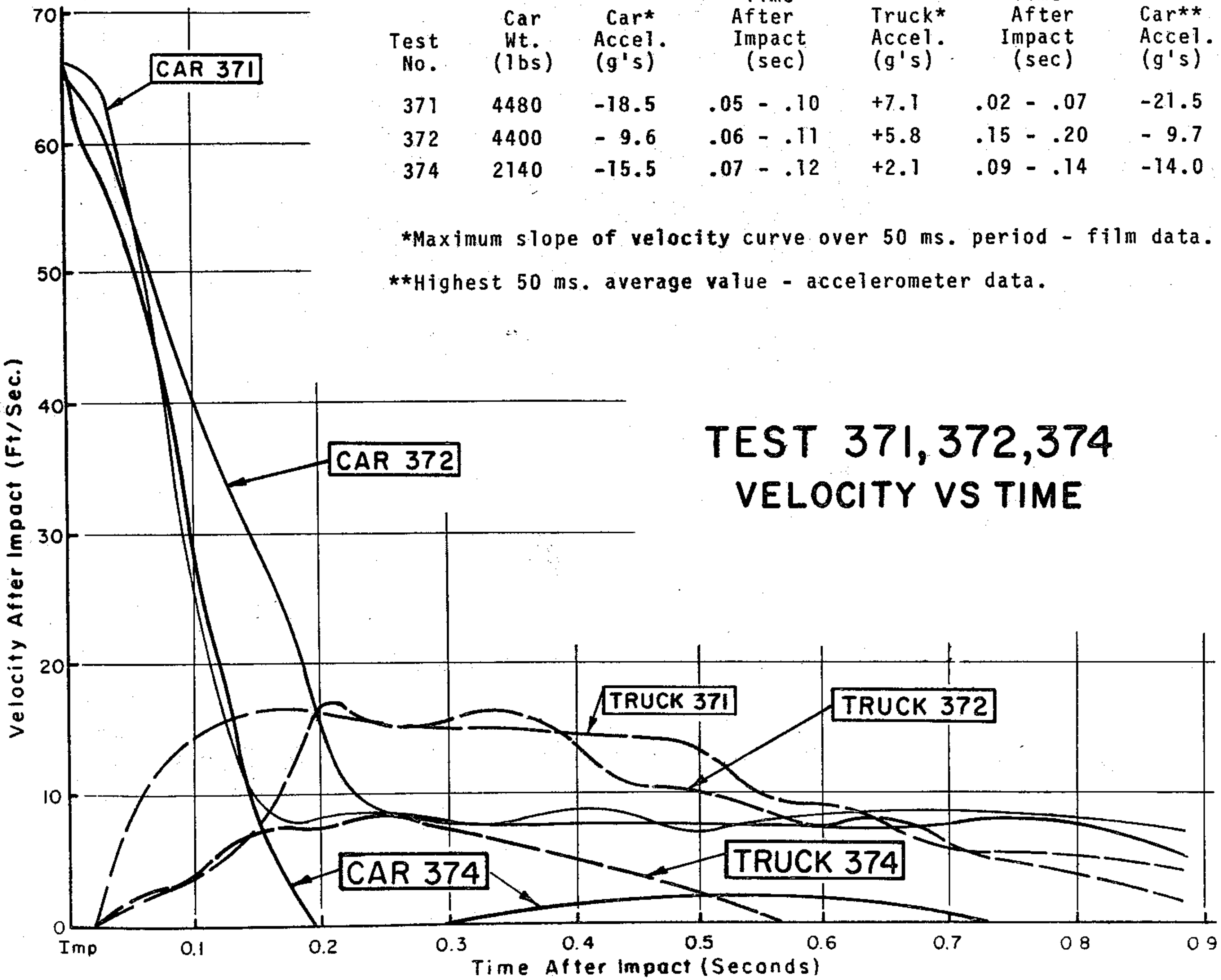


Figure 30, Velocity vs Time, Vehicles in Tests 374 and EAS-1

Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
374	2140	-15.5	.07 - .12	+2.1	.09 - .14	-14.0
EAS-1	2250	-17.7	.08 - .13	+3.2	.10 - .15	-12.2***

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

***Reported by Energy Absorption Systems, Inc.

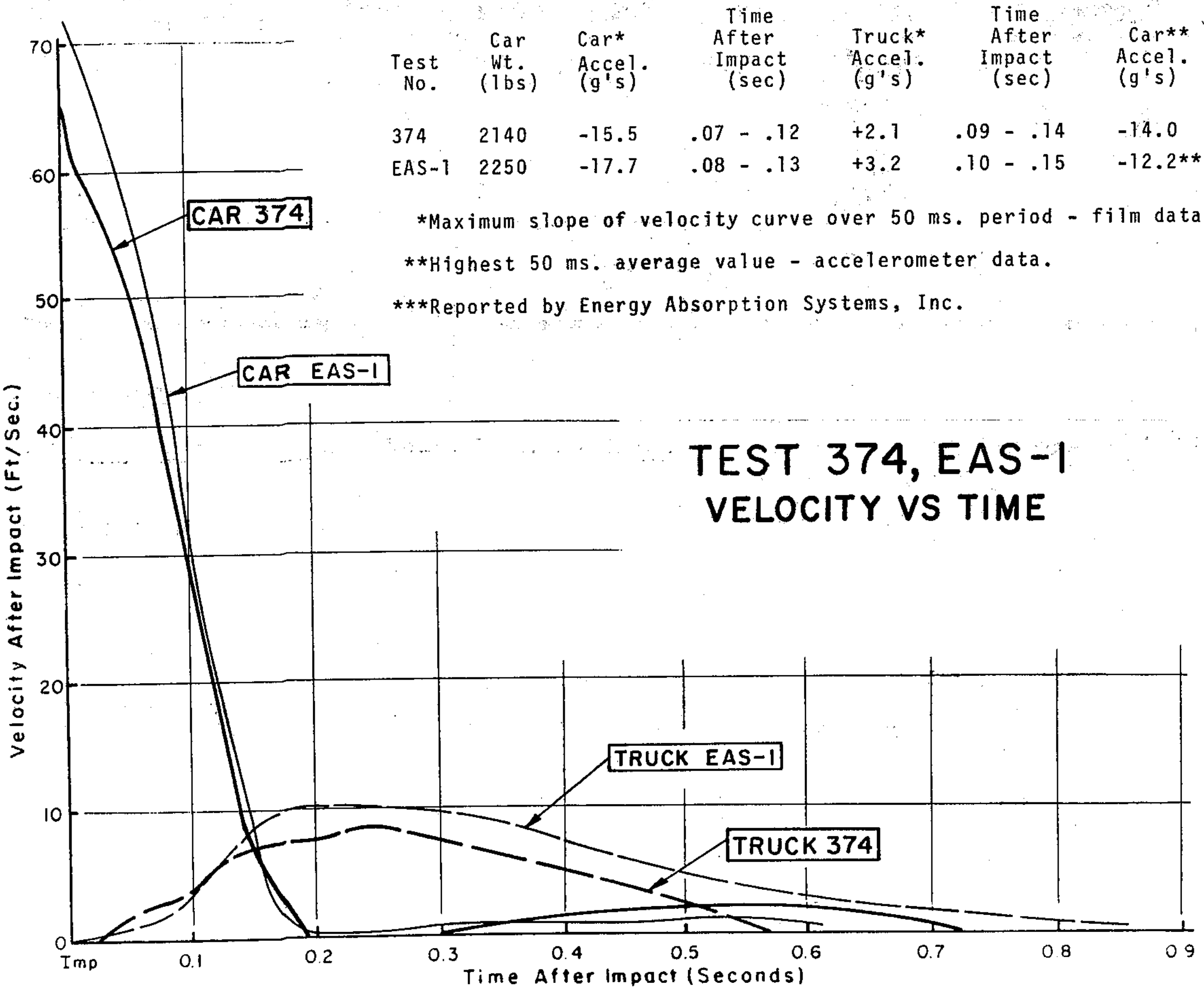


Figure 31, Velocity vs Time, Vehicles in Tests 372, 374, and 376

Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
372	4400	- 9.6	.06 - .11	+5.8	.15 - .20	- 9.7
374	2140	-15.5	.07 - .12	+2.1	.09 - .14	-14.0
376	1890	-19.4	.07 - .12	+2.7	.11 - .16	-17.9

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

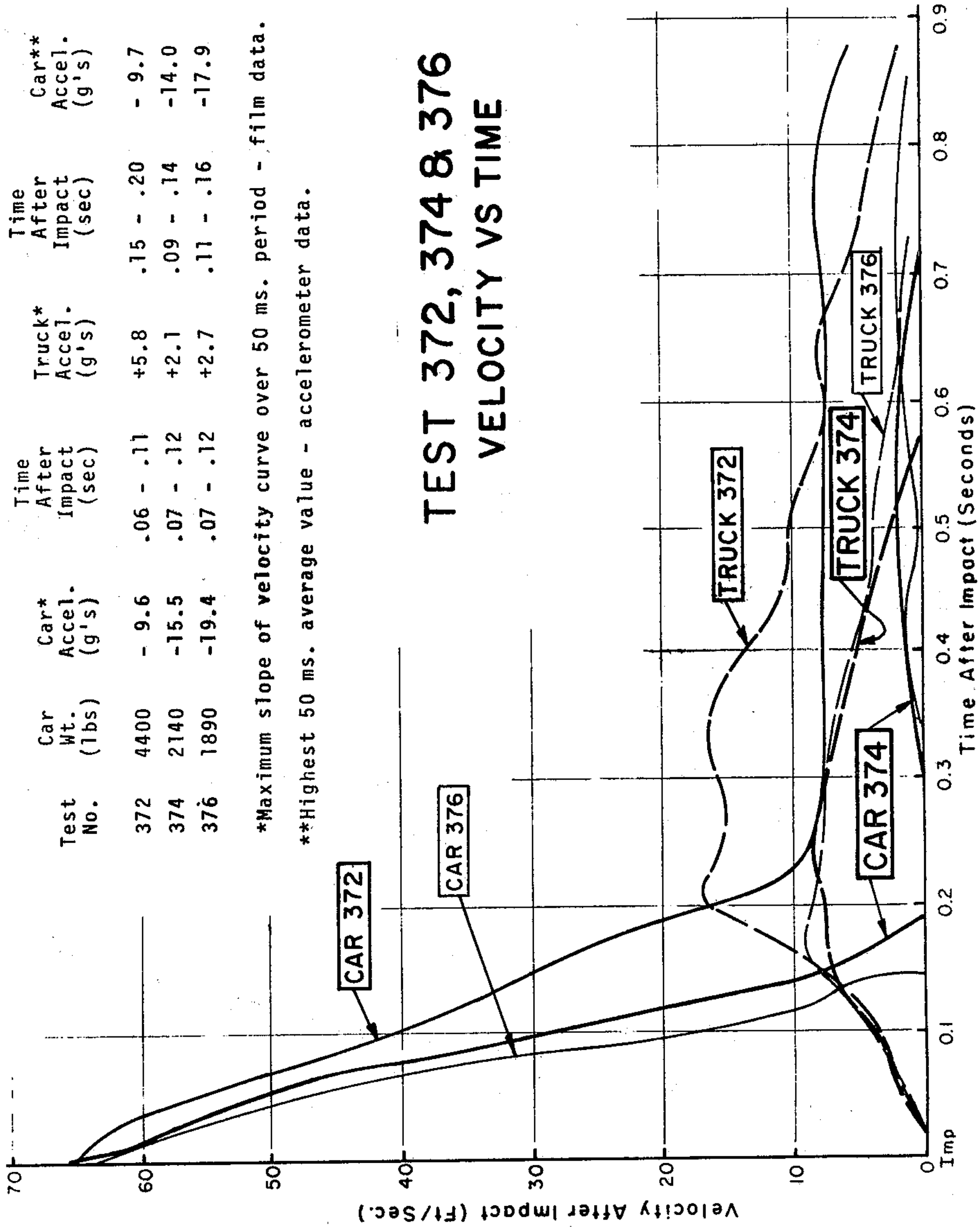


Figure 32, Velocity vs Time, Cars in Tests 371, 374, EAS-1, and 376

Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
371	4480	-18.5	.05 - .10	+7.1	.02 - .07	-21.5
374	2140	-15.5	.07 - .12	+2.1	.09 - .14	-14.0
EAS-1	2250	-17.7	.08 - .13	+3.2	.10 - .15	-12.2
376	1890	-19.4	.07 - .12	+2.7	.11 - .16	-17.9

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

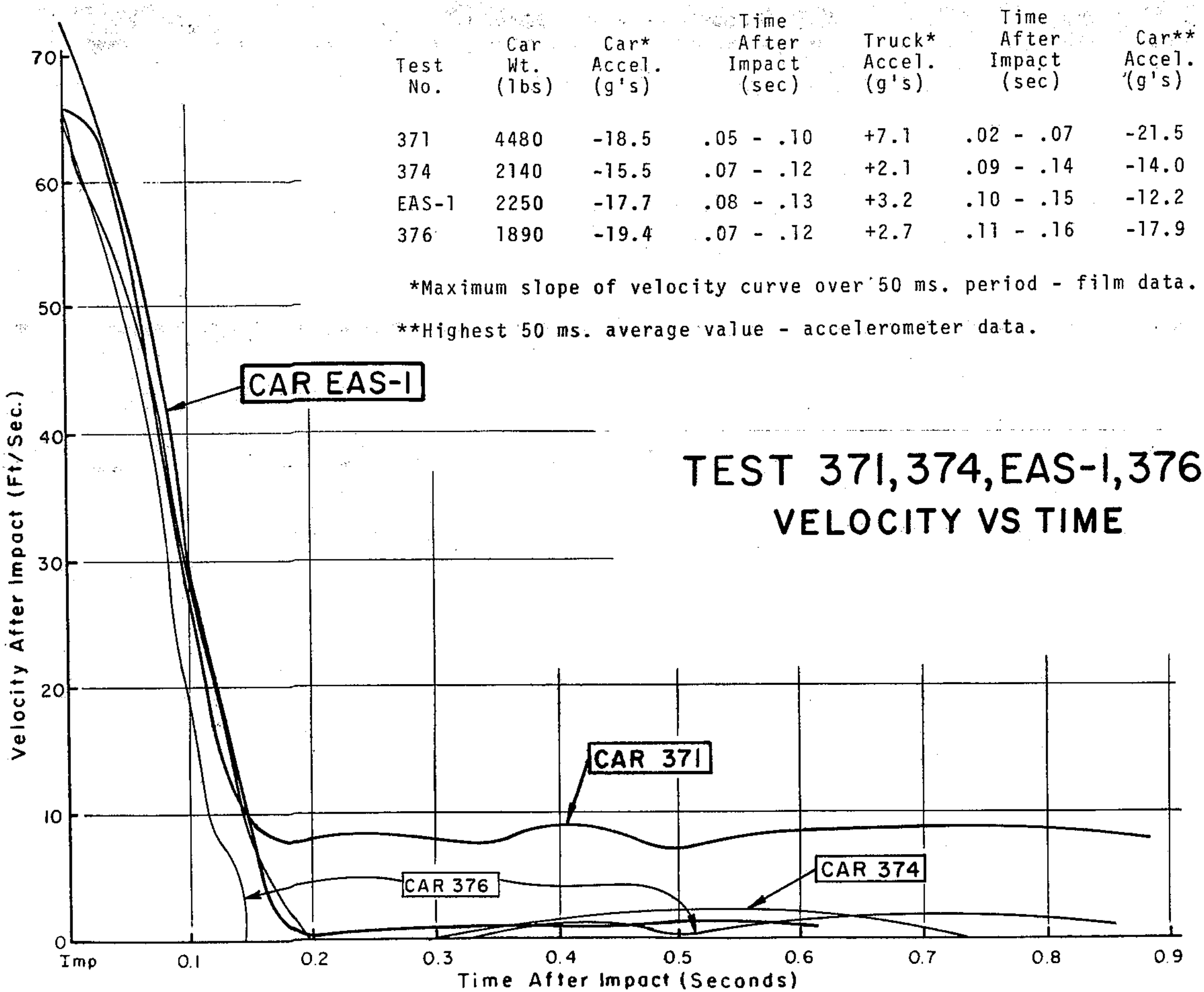
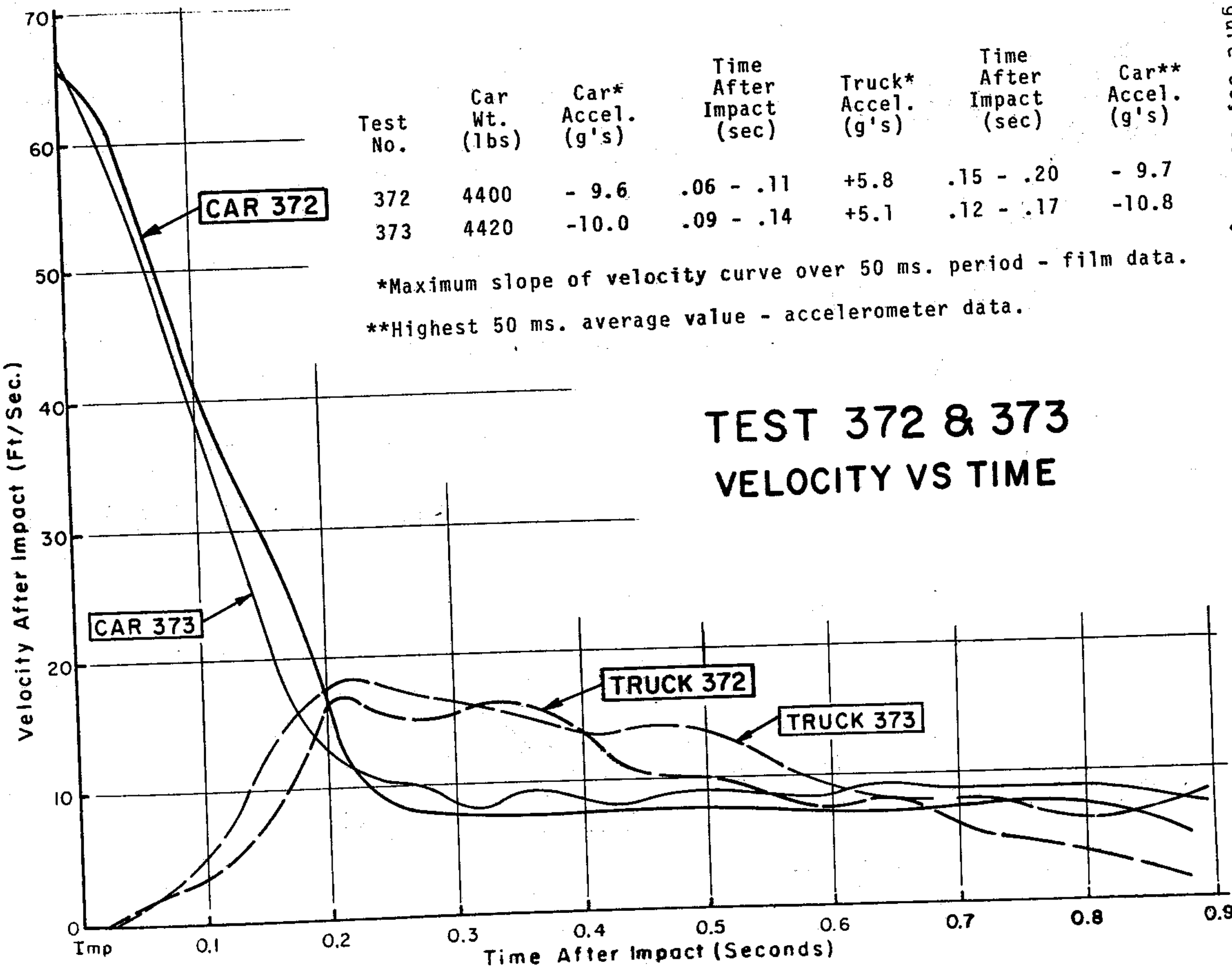


Figure 33, Velocity vs Time, Vehicles in Tests 372 and 373

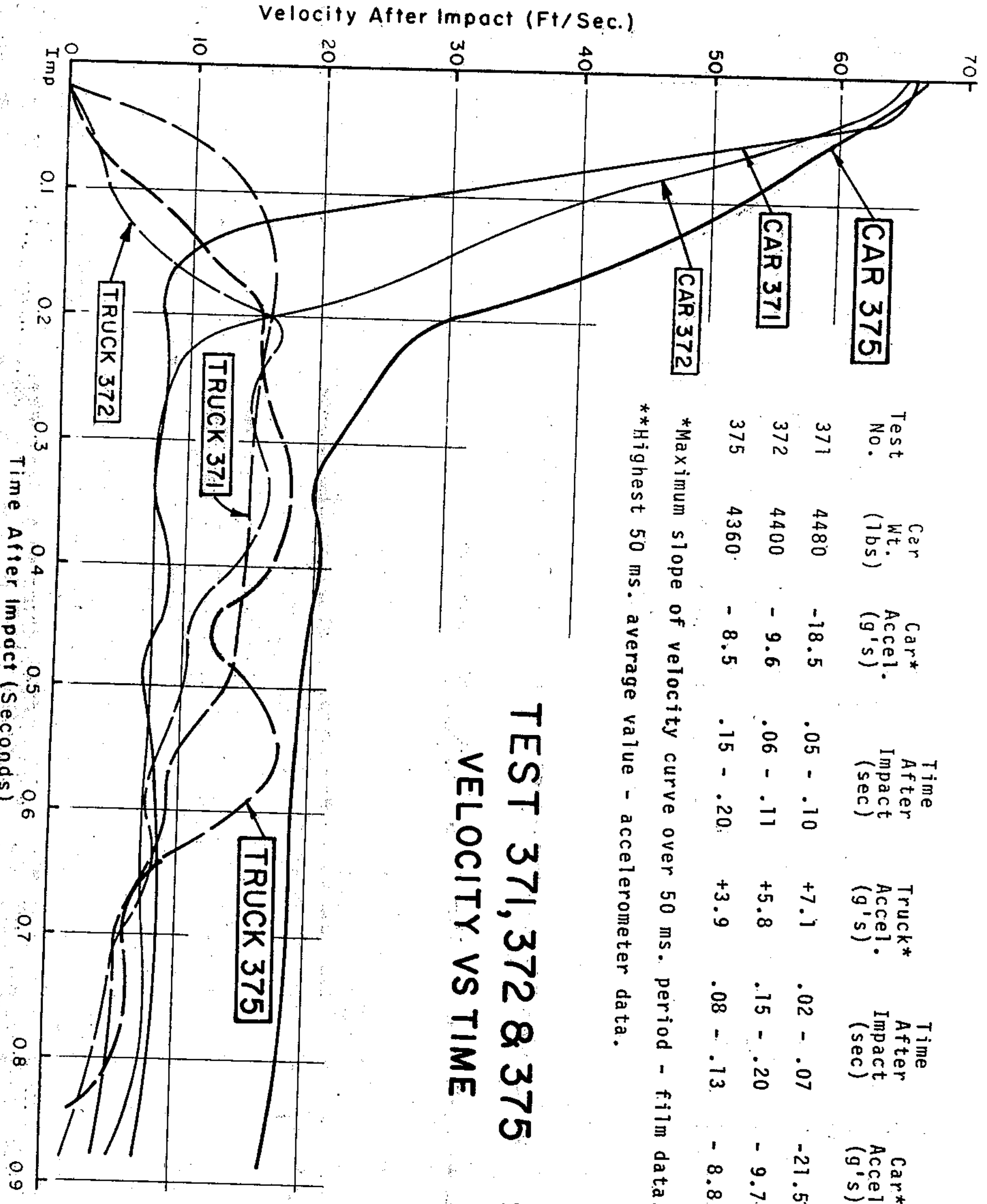


Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
372	4400	- 9.6	.06 - .11	+5.8	.15 - .20	- 9.7
373	4420	-10.0	.09 - .14	+5.1	.12 - .17	-10.8

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

Figure 34, Velocity vs Time, Vehicles in Tests 371, 372, and 375



Test No.	Car Wt. (lbs)	Car* Accel. (g's)	Time After Impact (sec)	Truck* Accel. (g's)	Time After Impact (sec)	Car** Accel. (g's)
371	4480	-18.5	.05 - .10	+7.1	.02 - .07	-21.5
372	4400	- 9.6	.06 - .11	+5.8	.15 - .20	- 9.7
375	4360	- 8.5	.15 - .20	+3.9	.08 - .13	- 8.8

*Maximum slope of velocity curve over 50 ms. period - film data.

**Highest 50 ms. average value - accelerometer data.

and highlight the severity of an impact when there is no TMA protection. 3) The average deceleration was also calculated using the car passenger compartment stopping distance. These values were somewhat lower than the two 50 ms average values. The accelerometer values were more conservative and are used to evaluate the TMA performance.

Figures 29 through 34 show velocity curves superimposed to compare a variety of test parameters. Figure 28 is included to show the amount of data scatter. Test 371, which is shown, had the most scatter of the plotted points of all the tests.

Figure 29 compares Tests No. 371, 372, and 374. It can be seen that the TMA was very helpful in reducing the deceleration in Test 372, the large car test, from that in the control test Test 371. The gains are not nearly as impressive in Test 374 where the acceleration of -14.0 g's is over the allowable value of -12 g's.

In Figure 30 the two Pinto tests are compared. Caltrans took movies of Test EAS-1 but did not have accelerometers mounted on the test car. Therefore, the values from film data will be used to evaluate the two tests since the data came from the same test equipment. The values of acceleration were over the -12 g allowable value in both tests. The value of -17.7 g's in Test EAS-1 was higher because of the higher impact speed of 49 mph. The decelerations from film data indicate that the more flexible steel grid support used under the TMA in Test EAS-1 did not have much, if any, effect on the deceleration.

Figure 31 compares the large, small, and very small car tests. They show progressively higher decelerations as the car weight decreases.

Figure 32 compares the control test with the three "small" car tests. These curves show the TMA provides minimal protection for the 1890 lb car in Test 376. A 2250 lb car traveling over 45 mph as in Test EAS-1 does not fare much better.

Figure 33 shows that there was little difference in decelerations of the test cars when the truck braking was changed from all wheels to rear wheels only.

Figure 34 was included to compare results of Test 375, the offset angular impact, with Test 371, the control test, and Test 372, the head-on large car test. The results for Tests 372 and 375 were quite similar and were satisfactory.

It should be emphasized that, although the deceleration values were computed to the closest 0.1 g, sometimes two accelerometers mounted side by side in the car will generate values that differ by 1 g. Therefore, when test values are compared, they should vary by approximately 2 g's or more before much significance is attached to the differences.

The decelerations from accelerometer data taken in the Connecticut tests were computed from small scale records in their final report (4) and may not be extremely accurate. They do show that the decelerations in the

Connecticut tests were higher than those in the comparable Caltrans tests despite the fact the truck wheels were not braked in the Connecticut tests and the trucks had longer stopping distances. This might be explained by heavier truck plus TMA weights of 16,000 lbs in Connecticut vs 13,140 lbs in California. Differences in instrumentation may have been a factor also.

The average decelerations based on the stopping distance of the passenger compartment do not have much value for comparing tests. For example in Table 2 the average accelerations for Tests 371 and 372 were both -4.9 g's, yet by all other means of comparison, Test 371 was much more severe.

Based on an analysis of the acceleration data, it can be concluded that for the test conditions of this study, the TMA was well designed for cars weighing close to 4500 lbs. If it is desired to favor lightweight or miniweight cars, the TMA needs to be softened, and possibly lengthened or attached to a lighter weight truck. Analysis of the acceleration data also leads to the conclusion that an impact speed of 45 mph even for heavy cars is the highest speed the TMA can handle effectively. This is related to the six foot length of the TMA as much as to the design of the crushable materials inside the TMA.

Dump trucks mounted with TMA's should carry little, if any, payload. Added truck weight would tend to increase the car deceleration levels.

5.3.3.2 Truck Acceleration

Rear end impacts not only decelerate the car, but force the truck to accelerate rapidly. Table 2 and Figures 29 through 34 give truck cab accelerations which vary from a maximum of 5.0 g's in Test 371, the control test without a TMA, down to 2.4 g's in Test 374, the lightweight car impact with a TMA (based on Caltrans and accelerometer data). These values are well below those of the car deceleration. The accelerometer records are contained in Appendix C.

Even though the accelerations are relatively low, they may still cause whiplash or other head injuries to truck drivers or passengers. This was evidenced in Test 374 where the dummy head snapped back and broke the rear window in the truck cab despite a maximum average acceleration of only 2.4 g's. Appendix F contains a discussion of whiplash and head restraints. The Office of Equipment has embarked on a program to develop and test head restraints that will minimize the effects of truck accelerations in rear end impacts.

Truck accelerations in the Connecticut tests were in the same range as those in the Caltrans tests.

The Caltrans truck accelerations based on film data were higher than those based on accelerometer data in the tests with heavy cars, but nearly the same in the tests with the lighter weight cars.

5.3.3.3 Dummy Decelerations

Accelerometers in the head of the dummy in the impacting passenger cars measured deceleration in three directions. The accelerometer records are reproduced in Appendix C. They show very high decelerations in Test 371, the control test, where the dummy was restrained by lap and shoulder belts, and Test 376, the 1890 lb car test, where the dummy was restrained only by a lap belt. Accelerations were in the -20 g or less range for Tests 372, 373 and 375, the three heavy car tests, and were higher in Test 374, the 2140 lb car test. These records indicate that the TMA helped to reduce dummy decelerations, and that the use of a shoulder belt is important, particularly in lightweight and miniweight cars.

Another way of evaluating possible injury to passengers is by using a "rattle space model". Reference 12 outlines the method which uses the record of displacement vs time from film data shown in Figure 35. A line with a slope representing a 45 mph impact speed is drawn through the origin. A parallel line is drawn starting at a displacement of -2.0 ft which represents the position of the head of a passenger which is allowed to move freely for two feet forward before striking the windshield or other interior car surface. The passenger's head maintains a speed of 45 mph during impact until it strikes the windshield. At some point this straight line representing head displacement crosses the curve representing the car passenger compartment displacement. At this time after impact, the passenger's head occupies the same point or position as the windshield. This time has been called the rattlespace time. The rattlespace time can be entered on the velocity curves to find the car velocity at that time which is subtracted from the passenger head velocity of 45 mph. This change in velocity, the relative velocity with which the passenger strikes the windshield, is then compared against a standard value.

The rattlespace time was also obtained by observing a sliding weight device attached to the right side of the car. It is described in Appendix B. The time after impact at which the weight had slid two feet was determined from film data, and could be entered in the velocity curves as described above. The two foot distance criterion was taken from Reference 1, but could be more or less depending on the size of the car passenger compartment, driver position, etc.

Following is a table of the rattlespace times determined by the above two methods, and the car velocity and relative passenger head velocity for the tests. No standard has been established for a maximum relative head velocity in a forward direction, but values in the range of 10-40 fps have been proposed by other researchers in the field.

Test No.	Impact Velocity (fps)	Displacement Curve Data: Rattle-space Time (sec)	Car Velocity (fps)	Relative Head Velocity (fps)	Sliding Weight Data: Rattle-space Time (sec)	Car Velocity (fps)	Relative Head Velocity (fps)
371	66	0.115	20	46	0.128	14	52
372	66	0.130	33	33	0.165	26	40
373	66	0.125	31	35	-	-	-
374	66	0.105	27	39	0.101	29	37
EAS-1	72*	0.110	26	46	-	-	-
375	66	0.160	40	26	-	-	-
376	65*	0.100	18	47	0.105	15	50

*For these tests the slope of the head displacement line had to be changed slightly to reflect a car impact velocity different than 66 fps.

The table shows that the values of 33, 35 and 26 fps for large car Tests 372, 373 and 375 are in the high end of the acceptable range (using displacement curve data). In all the other tests the relative head velocities nearly equal or exceed the maximum value of 40 fps. The relative head velocities based on sliding weight data are slightly higher but similar. Although there is no established standard for maximum relative head velocity, it is clear that this data reinforced other data in the report: the TMA is near the upper limit of its capacity in handling heavy cars traveling 45 mph, and presents a severe environment for impacting light weight cars.

5.3.4 Vehicle Trajectory: Truck Roll Ahead and Car Position

Guidelines from Table 4 of TRC No. 191 (1) are as follows:

"A. After impact, the vehicle trajectory and final stopping position shall intrude a minimum distance into adjacent traffic lanes.

The accompanying text also states,

> "A subjective appraisal shall be made by the test engineer as to the trajectory hazard, based on vehicle exit speed and angle, maximum intrusion into a traffic lane or lanes during trajectory, and post crash controllability."

5.3.4.1 Truck Roll Ahead

One of the key objectives of this study was to determine truck roll ahead. Table 1 gives the roll ahead distances for both the car and truck in all tests. For both front and rear truck wheels braked, the maximum truck roll ahead was 7.9 feet caused by impact from the heavy car in Test 372. Roll ahead was more in Test 373 when the front truck wheels were not braked, and in the Connecticut tests where no wheels were braked. Roll ahead was also more in Test 371 where no TMA was used because the impacted mass was less. Figure 35 shows the displacement vs time during impact of the car and truck for all tests based on film data.

The truck roll ahead (or stopping) distances in Tests 371, 372, and 374 agreed quite well with theoretical values assuming a coefficient of friction between truck tires and pavement of 0.7 and assuming the truck wheel brakes were all locked. Curves of theoretical values of truck stopping distances for various weights and speeds of cars, various truck weights, and coefficients of friction of 0.7, 0.6 and 0.5 are shown in Figures 36-38.

Figure 35, Displacement vs Time, Vehicles, All Tests

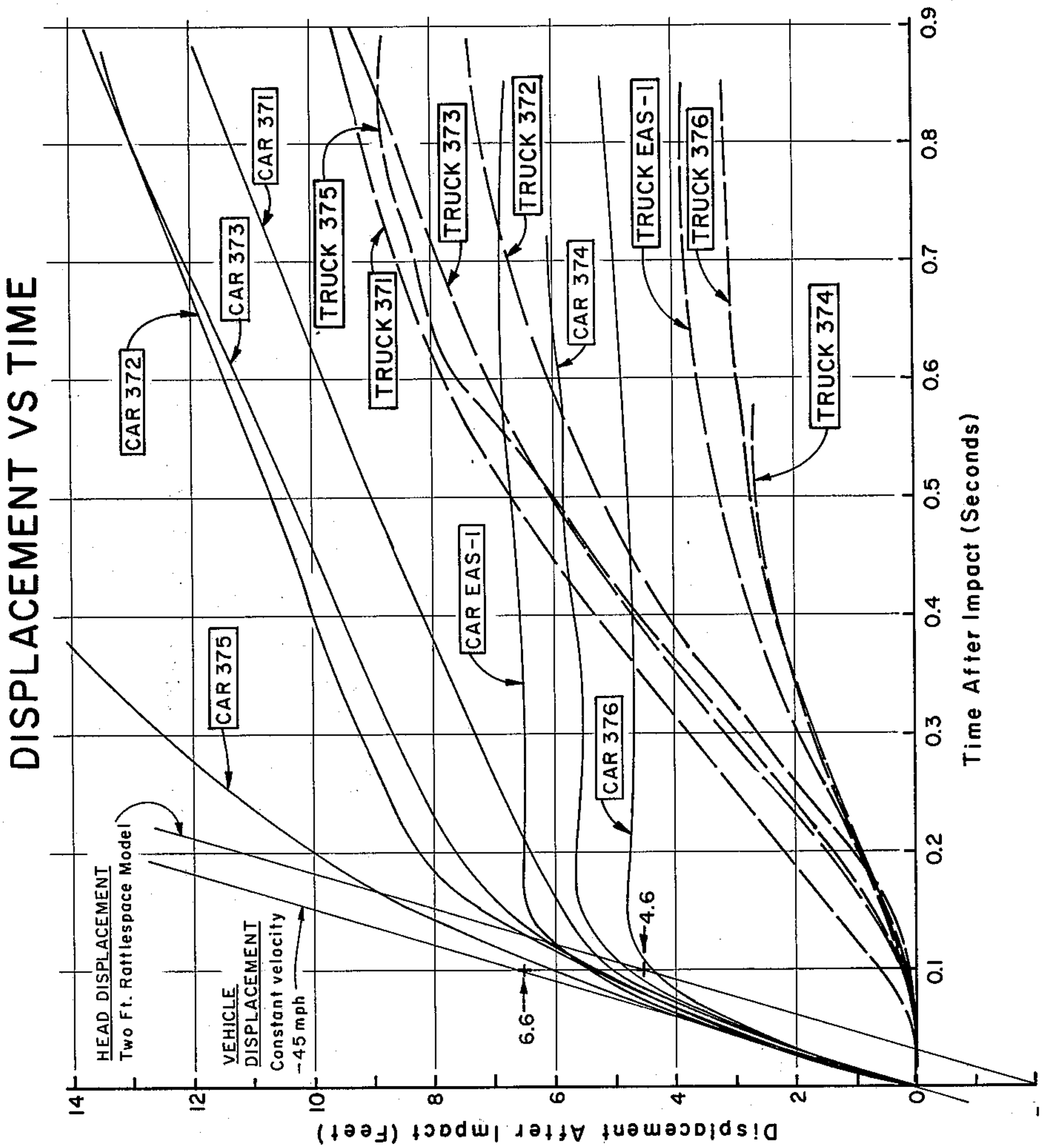


Figure 36
Truck Stopping Distance, Coefficient of Friction = 0.7

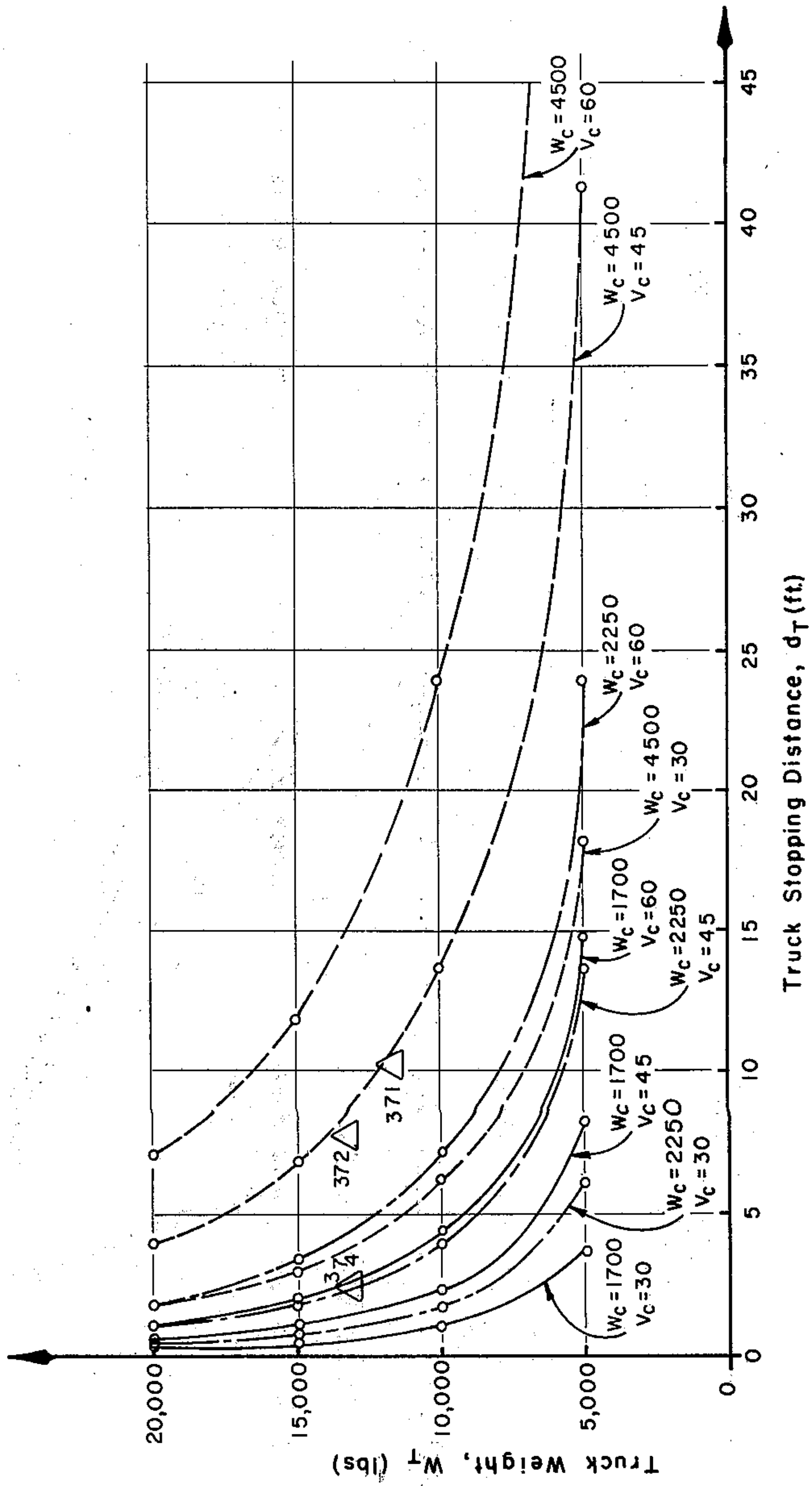


Figure 37
Truck Stopping Distance
Coefficient of Friction = 0.6

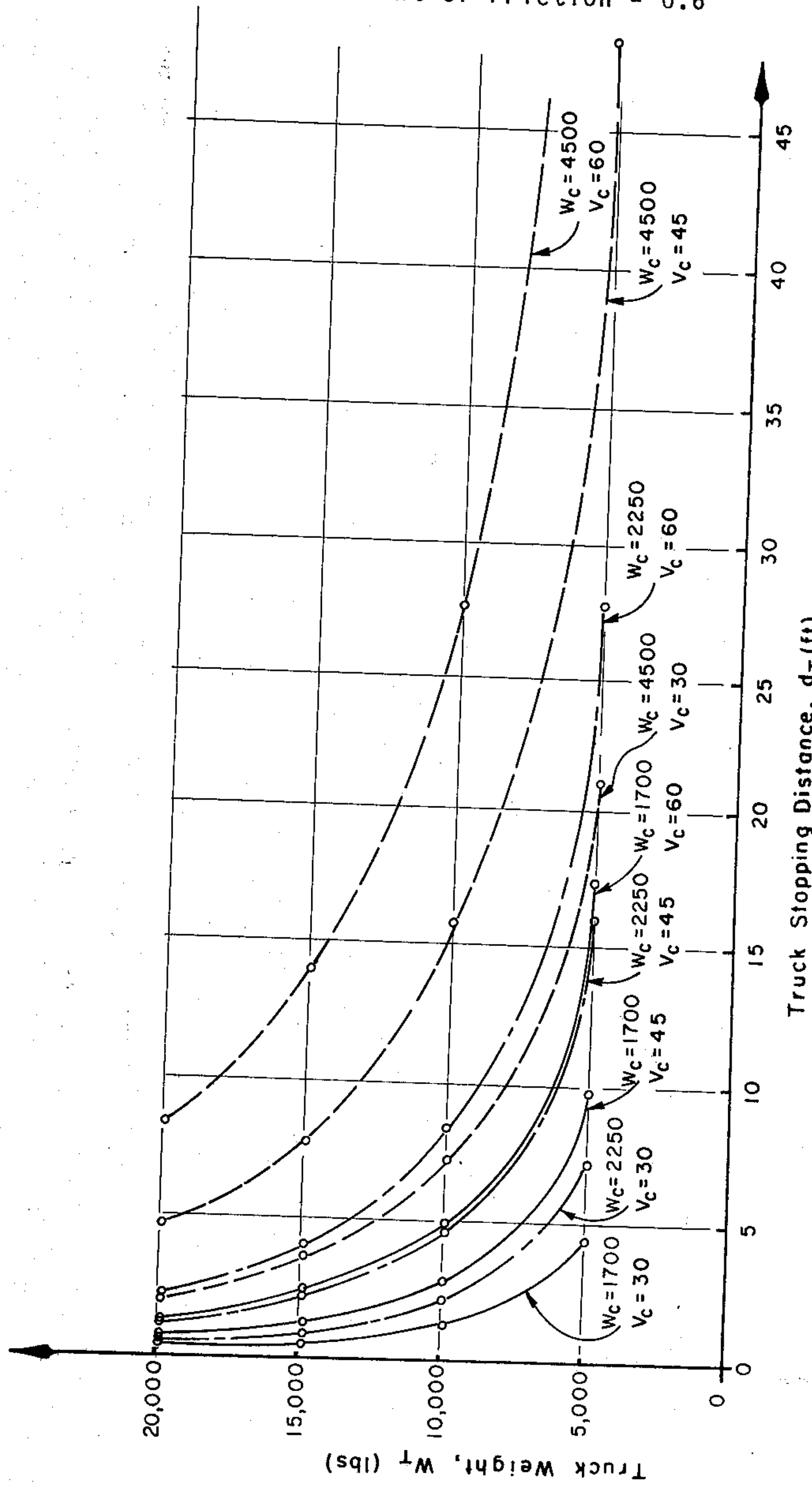
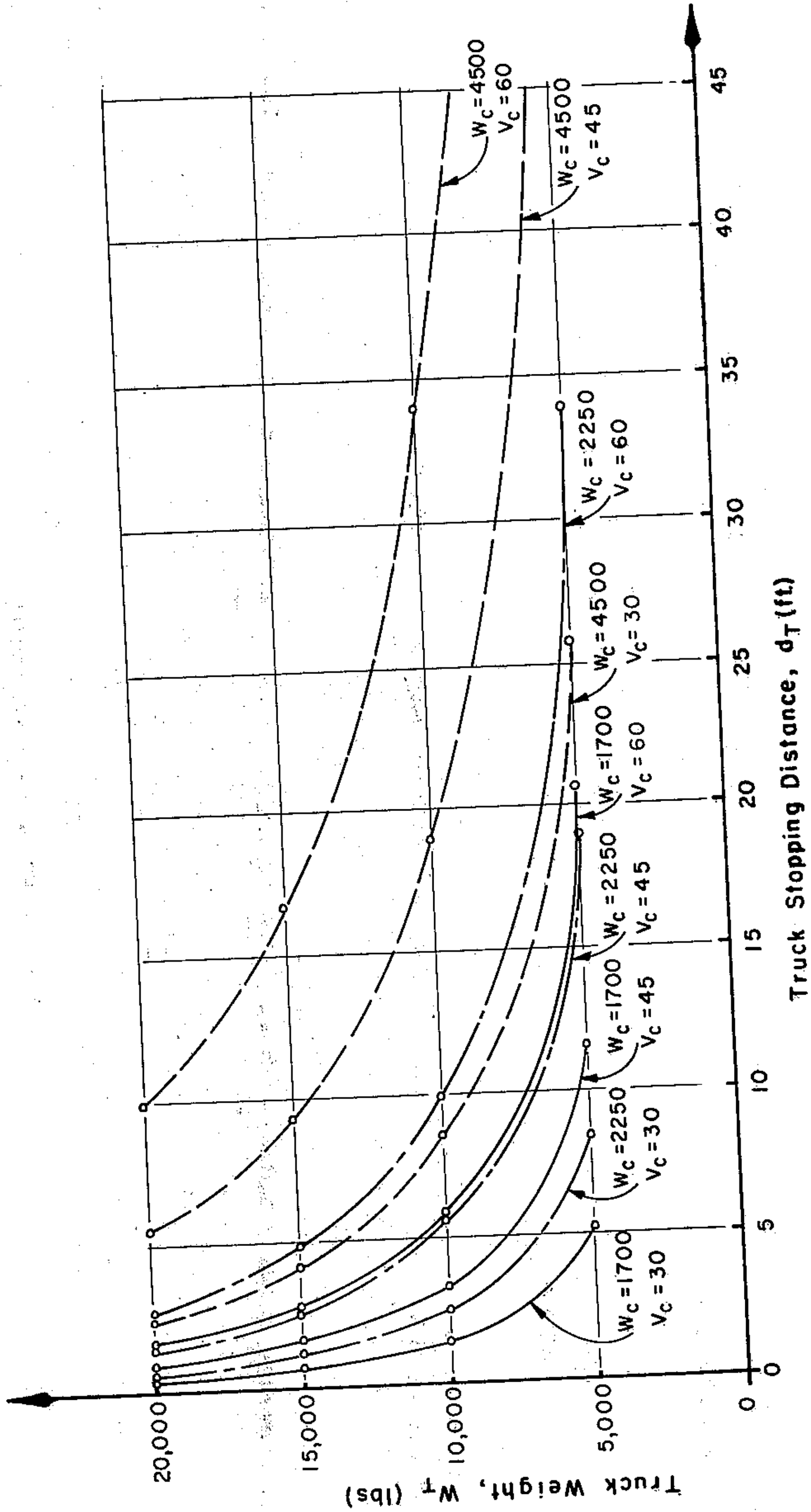


Figure 38
Truck Stopping Distance, Coefficient of Friction = 0.5



The formulas used were as follows:

$$W_{T+C} = W_T + W_C$$

$$V_{T+C} = \frac{W_C V_C}{W_{T+C}}$$

$$K.E._{T+C} = \frac{W_{T+C} V^2_{T+C}}{64.4}$$

$$d_T = \frac{K.E._{T+C}}{W_T \mu}$$

where: W_T = weight of truck (plus TMA if one is attached to truck), lbs

W_C = weight of car, lbs

W_{T+C} = weight of truck plus car (plus TMA), lbs

V_C = speed of car just before impact, fps

V_{T+C} = speed of car and truck after impact, fps

$K.E._{T+C}$ = kinetic energy of car and truck after impact, ft-lbs

μ = coefficient of friction between truck tires and pavement

d_T = stopping distance of truck, ft.

It is assumed here that after impact, the car and truck are both traveling at a speed of V_{T+C}, and they are both stopped by the frictional force between the truck tires and pavement. Other factors would have some effect on d_T such as frictional forces on the car tires, roadway slope, etc.

The curves do serve as a rough guide if it is desired to park a truck a safe distance back of workers or some specific object. Depending on the coefficient of friction, the truck stopping distance for impacts by a 4500 lb car traveling 60 mph varies from 24 to 34 feet. It would be less for smaller cars and lower speeds. A safe working distance would be <u>more</u> than 34 feet. Unfortunately, if workers were 40 to 50 feet ahead of a truck, they then would be vulnerable to errant vehicles that angle across the roadway in front of the truck. Also, even this distance would be inadequate if the truck and TMA were struck from behind by a heavy vehicle or bus which might weigh ten to fifteen times as much as a 4500 lb car. It should be emphasized that the TMA does not have any effect on truck stopping distance other than reducing it slightly by adding mass to the truck mass which affects the change of momentum formulas.

The roll ahead truck distance was somewhat larger in the Connecticut tests because the truck wheels were not braked in their tests. Their trucks were all in second gear, however, the same as for the Caltrans tests.

5.3.4.2 Truck Wheel Sliding and Rolling

In all tests the rear truck wheels were braked. During impact they slid and rotated. Rear wheel maximum rotation was taken from the test movies as follows:

Test No.	Truck Rear Wheel Rotation
371	88°
372	110°
373	298°
374	43°
EAS-1	47°
375	31°
376	69°

In several tests only one of the rear wheels could be seen clearly to determine rotation. The front wheels also displayed a combination of rotating and sliding except in Test 373 where the unbraked front wheels rolled the entire distance. Rear wheel rotation was extra high in Test 373, presumably because roll ahead distance was the greatest in this test.

5.3.4.3 Effect on Adjacent Traffic

In all tests except Test 375 the car and truck traveled a short distance in a straight line. The car stayed directly behind the truck. Therefore, the effect on adjacent traffic would have been minimal. Even in Test 375, the offset angular impact, the car stayed as close to the truck as could be expected.

6. REFERENCES

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3. Jung, F. W., "Design of Barrel Trailer for Maximum Collison Protection," Transportation Research Board, Transportation Research Record No. 631, 1977, pp. 76-81.

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7. Stoughton, R. L., J. R. Stoker and E. F. Nordlin, "Dynamic Test of a Truck Mounted Crash Cushion," California Department of Transportation, Transportation Laboratory, September 1975.

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9. Stoughton, R. L., D. M. Parks, J. R. Stoker, and E. F. Nordlin, "Energy Absorbing Highway Barrier Material Investigations," California Department of Transportation, Transportation Laboratory, June 1977.

10. "Collision Deformation Classification, Recommended Practice J224a", 1973 Handbook, Society of Automotive Engineers, New York, 1973.

11. "Vehicle Damage Scale for Traffic Accident Investigators," Traffic Accident Data Project Bulletin No. 1, National Safety Council, 1968.

12. Chisholm, D. B., and L. C. Meczkowski, "Dynamic Testing of Luminaire Supports with an Improved Pendulum Impact Facility," Report No. FHWA-RD-78-204, Federal Highway Administration, September 1978.

APPENDIX A: Test Vehicle Equipment and Guidance Methods

- Two 12-volt wet cell lead acid motorcycle-type batteries were mounted in the trunk to supply power for the test equipment in the car.

- The test vehicle gas tank was disconnected from the fuel supply line and drained. In Tests 371-373 and 375 the tank was filled with water to add weight to the car and eliminate the fire hazard. In Tests 374 and 376, extra weight was not needed, so dry ice was placed in the empty tank to inhibit combustion. A one-gallon safety gas tank was installed in the trunk compartment and connected to the fuel supply line.

- The accelerator pedal was linked to a small cylinder with a piston which opened the throttle. The piston was activated by a manually thrown switch mounted on the top of the rear fender of the test vehicle. The piston was connected to the same CO_2 tube used for the brake system, but a separate regulator was used to control the pressure. The car was placed in second gear for the run in.

- A speed control device connected between the negative side of the coil and the battery of the vehicle regulated the speed of the test vehicle based on speedometer cable output. This device was calibrated prior to the test by conducting a series of trial runs through a speed trap composed of two tapeswitches set a known distance apart connected to a digital timer.

• A cable guidance system was used to direct the vehicle into the barrier. The guidance cable, anchored at each end of the vehicle path to a threaded coupler embedded in a concrete footing, passed through a guide bracket bolted to the spindle of the right front wheel of the vehicle. A steel knockoff bracket, anchoring the end of the cable closest to the barrier to a concrete footing, projected high enough to knock off the guide bracket, thereby releasing the vehicle from the guidance cable prior to impact.

• A micro switch was mounted below the front bumper and connected to the ignition system. A trip plate placed on the ground near impact triggered the switch when the car passed over it. This opened the ignition circuit, cut the vehicle engine prior to impact, and released the sliding weight from an electro-magnet so the weight was free to travel slightly before the instant of impact.

• A solenoid-valve actuated CO_2 system was used for remote braking after impact or for emergency braking any other time. Part of this system was a cylinder with a piston, which was attached to the brake pedal. The pressure used to operate the piston was regulated according to the test vehicle's weight, to stop the test vehicle without locking up the wheels.

• The remote brakes were controlled at the console trailer by using an intrumentation cable connected between the vehicle and the electronic instrumentation trailer, and a cable from that trailer to the console trailer. Any loss of continuity in these cables caused an automatic activation of the brakes and ignition cutoff. Remote activation of the brakes also would turn off the ignition.

APPENDIX B: Photo-Instrumentation

Data film was obtained by using five high speed Photo-Sonics Model 16 mm-1B cameras, 200-400 frames per second (fps), and four high speed Redlake Locam cameras, 400 fps. These cameras were located around the impact area as shown in Figure B1. These cameras were electrically actuated from a central control console located adjacent to the impact area, except for three which had their own battery power and were turned on by three separate operators.

All high speed cameras were equipped with timing light generators which exposed reddish timing pips on the film at a rate of 1000 per second. The pips were used to determine camera frame rates and to establish time-sequence relationships. Data from the high-speed movies was reduced on a Vanguard Analyzer.

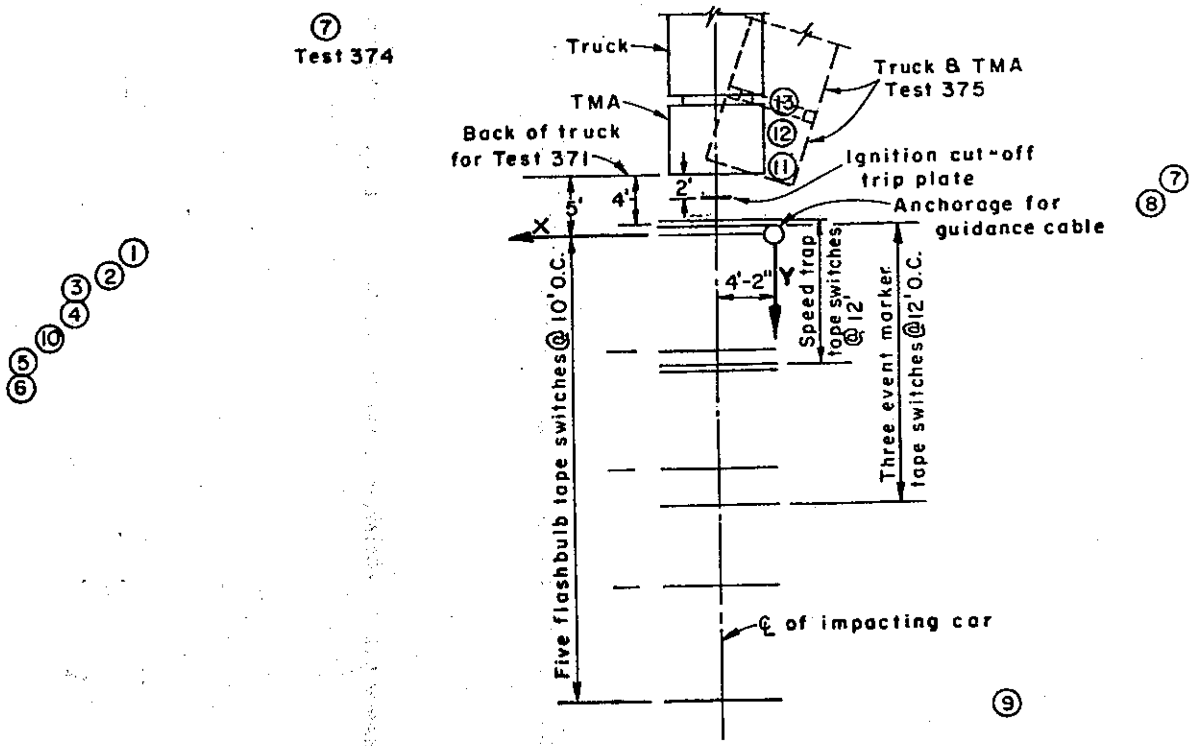
Camera 7 used in Test 374 was aimed at the dummy in the truck to view the motion of the head as it snapped back after impact.

Some procedures used to facilitate data reduction for the test are listed as follows:

1. Butterfly targets were attached to the test car, truck and TMA. Figures B2 and B3 show the target location dimensions.

2. Flashbulbs, mounted on the test vehicle, were electronically flashed to establish (a) initial vehicle/barrier contact (b) application of the vehicle's brakes and (c) beginning and end of sliding weight travel. The impact flashbulbs have a delay of several milliseconds before lighting up.

Figure B1 , CAMERA AND TAPESWITCH LAYOUT



CAMERA DATA

No.	Coord. (ft) x	y	Type	Lens	Speed (Frames/ sec)	Mounting
1	82	1	Redlake Locam 16mm	50mm	400	Tripod
2	96	3	Redlake Locam 16mm	25mm	400	Tripod
3	100	4	Redlake Locam 16mm	38mm	400	Tripod-Pan
4	100	4	Bolex 16mm	18mm	24	Tripod-Pan
5	115	15	Hulcher 70mm	150mm	20	Tripod
6	115	15	Hulcher 35mm	105mm	20	Tripod
7	-82	-6	Photo-Sonics 16mm-1B	13mm	350	Tripod
8	-76	-2	Redlake Locam 16mm	50mm	400	Tripod
9	-27	192	Photo-Sonics 16mm-1B	4 in.	200	Tripod
10	108	8	Videotape	-	-	Tripod
11	0	-11	Photo-Sonics 16mm-1B	13mm	400	Tower
12	0	-11	Photo-Sonics 16mm-1B	13mm	400	Tower
13	0	-11	Photo-Sonics 16mm-1B	13mm	400	Tower

NOTES:

The cameras were at the same locations for all tests except as noted.

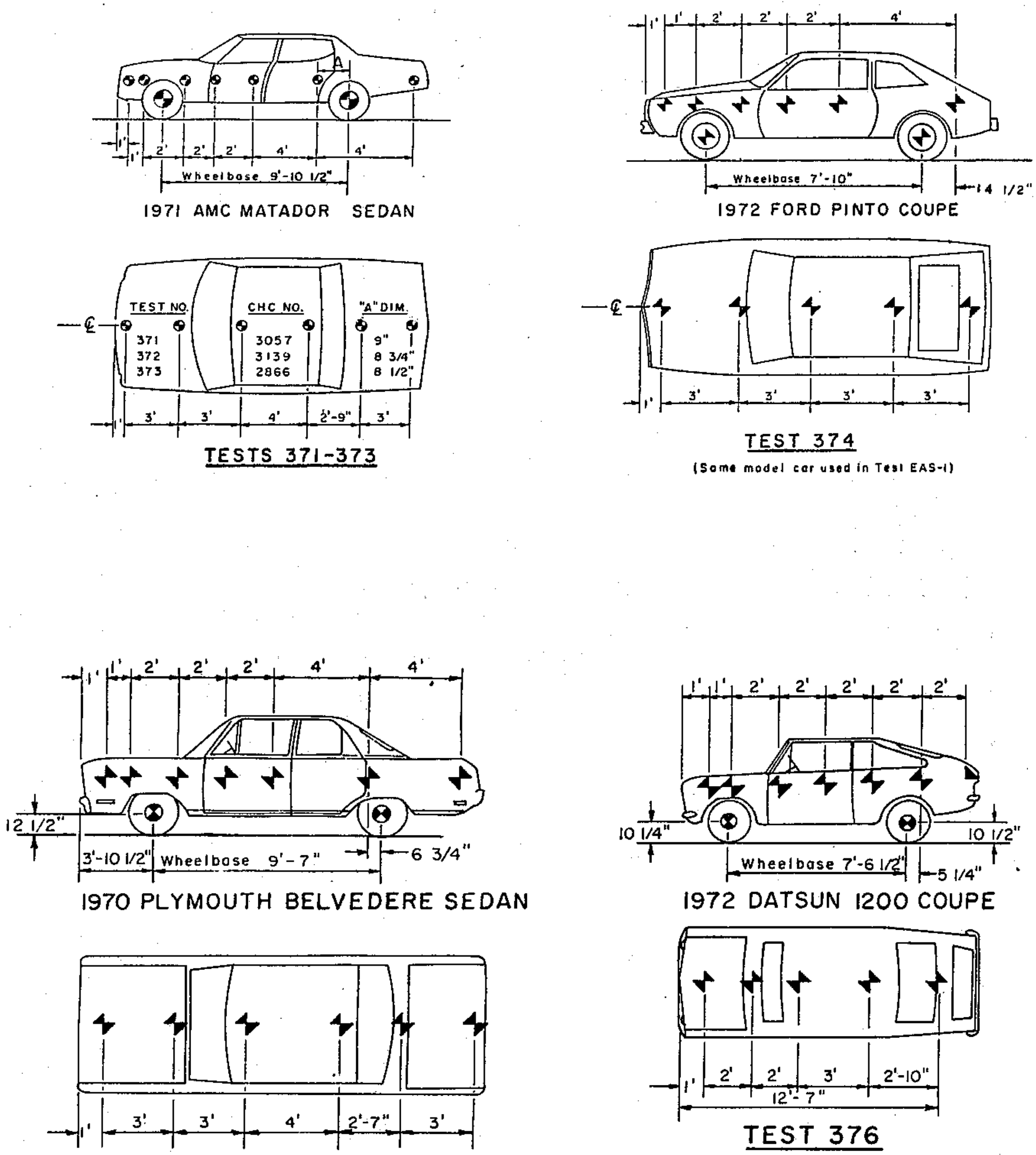
Test 371: Camera 7, x = -94; Cameras 11, 12, and 13 - not used.

Test 374: Camera 7, x = 50, y = 45; Camera 8, x = -90.

Test 375: Camera 7, x = 96, y = -29.

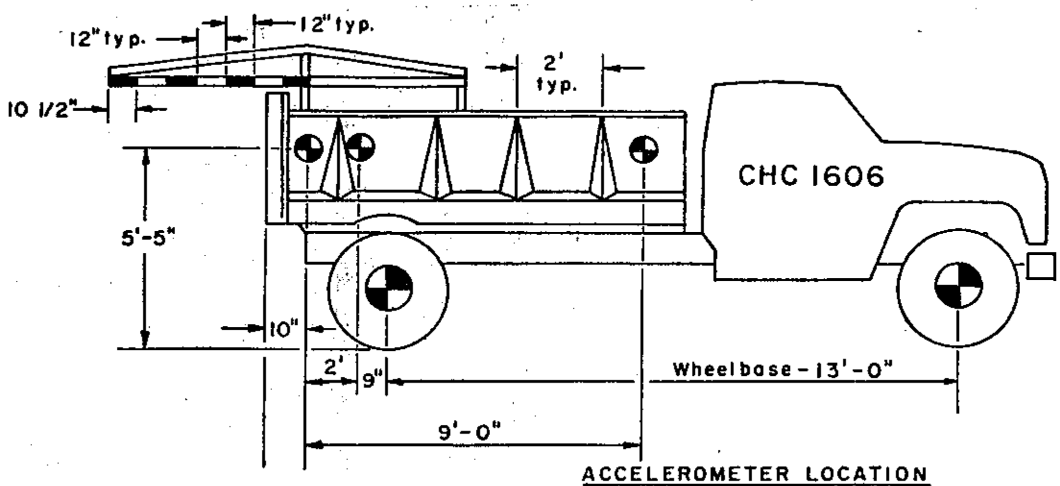
The videotape camera was not used for all tests. The camera speeds given are approximate. Exact speeds for the cameras were determined for each test during data reduction.

FIGURE B2, TEST CAR TARGETING AND DIMENSIONIONS



Note:
Drawings not to scale

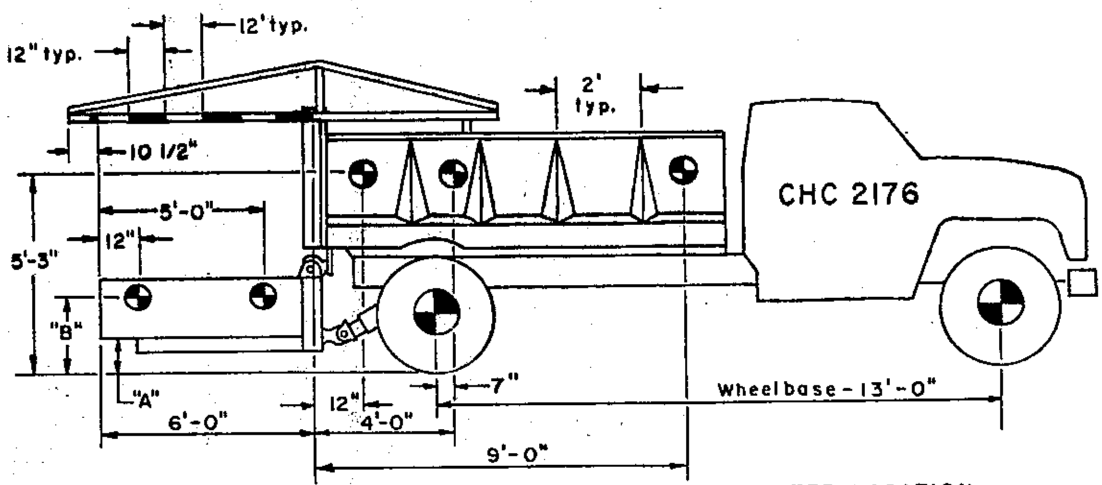
Figure B3, TRUCK TARGETING AND DIMENSIONS



ACCELEROMETER LOCATION

120" Forward of rear axle on passenger compartment floor near left door jamb.

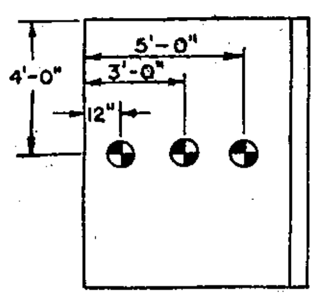
TEST 371



ACCELEROMETER LOCATION

120" Forward of rear axle on passenger compartment floor near left door jamb.

TEST 372-376



ATTENUATOR TOP VIEW

Truck Data - All Tests

Ford F-750
Four cu. yd. dump body
Rated Gross Vehicle Wt. = 25,000 lb.
Truck Wt. = 11,600 lbs - Test 371
11,740 lbs - Tests 372, 373, 375, 376
11,900 lbs - Test 374
TMA Wt. = 1,400 lbs - Tests 372-376

Variable Dimensions - Tests 372-376

Test No.	"A"	"B"
372	14 in.	32 in.
373	13	25
374	12.5	23.5
375	12	24
376	12	25
EAS-1	13	N.A.

All drawings not to scale

3. Five tape switches, placed at ten foot intervals, were attached to the ground perpendicular to the path of the impacting vehicle beginning about five feet from impact. Flashbulbs were activated sequentially when the tires of the test vehicle rolled over the tape switches. The flashbulb stand was placed in view of most of the data cameras or made visible to the tower cameras through the use of mirrors. The flashing bulbs were used to correlate the cameras with the impact events and to calculate the impact speed independent of the electronic speed trap.

Additional coverage of the impacts was obtained by a 70 mm Hulcher sequence camera and a 35 mm Hulcher sequence camera (both operating at 20 frames per second). Documentary coverage of the tests consisted of normal speed movies and still photographs taken before, during and after the impact.

Figure 24 shows the sliding weight device used to determine the rattlespace time as defined in Section 5.3.3.3. The weight contains ball bearings which roll along a smooth rod. The weight is held in place on the left end of the rod by an electronmagnet before impact. The front bumper switch on the car which cuts the ignition about two feet before impact also cuts off the current to the electromagnet. The weight is then free to slide forward for a two foot distance on the rod after impact. The time it takes for the weight to travel two feet (rattlespace time) is determined from the high speed movie film. Flash bulbs mounted on the device are activated when the weight begins to move and also when it reaches the end of its travel. The flashbulbs are more visible to distant data cameras than the sliding weight.

[illegible]

APPENDIX C: Electronic Instrumentation and Data

Table C1 gives the locations of the accelerometers in the test cars and trucks. Three Endevo Model 2262-200 piezo-resistive accelerometers were mounted in the head of the dummy. Statham unbonded strain gage type accelerometers were mounted on steel angle brackets which were welded to the floor of the cars and trucks. Those in the car were close to the center of gravity in the horizontal plane; those in the truck were on the left edge of the cab where they received solid support from the truck frame. The accelerometers in the truck are shown in Figure C1. The dummy accelerometers were mounted inside the head cavity.

Data from all transducers in the test vehicle were transmitted through a 1000 foot Belden #8776 umbilical cable connecting the vehicle to a 14-channel Hewlett Packard 3924C magnetic tape recording system. This recording system was mounted in an instrumentation trailer located in the test control area.

Three tape switches, activated by the weight of the car, were spaced 12 ft apart on the ground near the TMA. Closure of these switches made an event blip on the accelerometer data tape and helped to isolate the time of impact. A tape switch on the front bumper of the car closed at the instant of impact and activated flash bulbs mounted on the car. The closure of the bumper switch also put a blip on the event channel of the data tape to show the time of impact. Two other tape switches were placed 12 ft apart near the TMA and were attached to digital readout equipment to give an instant value of impact speed from the test car.

TABLE C1, ACCELEROMETER DATA

Date Channel No.	Test No.	Accel. Serial No.	Range (g's)	Location	Orientation
1	371	586	50	Car	Long.
1	372,373	589	50	Car	Vert.
1	374,376	590	100	Car	Vert.
1	375	589	50	Car	Lat.
2	371	589	50	Car	Long.
2	372-4,376	591	100	Car	Long.
2	375	590	100	Car	Vert.
3	371	DG66	200	Truck	Long.
3	372-4,376	1029	100	Car	Long.
3	375	591	100	Car	Long.
4	371	AN92	200	Truck	Long.
4	372-4,376	DG66	200	Truck	Long.
4	375	1029	100	Car	Long.
5	374	AN92	200	Truck	Long.
5	375	DG66	200	Truck	Long.
5	376	AN92	200	Truck	Lat.
6	375	AN92	200	Truck	Lat.
7	371	EW21	200	Dummy	Long.
7	372-6	EW69	200	Dummy	Lat.
8	371	EW46	200	Dummy	Vert.
8	372-6	EW21	200	Dummy	Long.
9	371	EW69	200	Dummy	Lat.
9	372-6	EW46	200	Dummy	Vert.

Note: Long. = Longitudinal (parallel to long axis of vehicle),
Lat. = Lateral (perpendicular to long axis of vehicle).

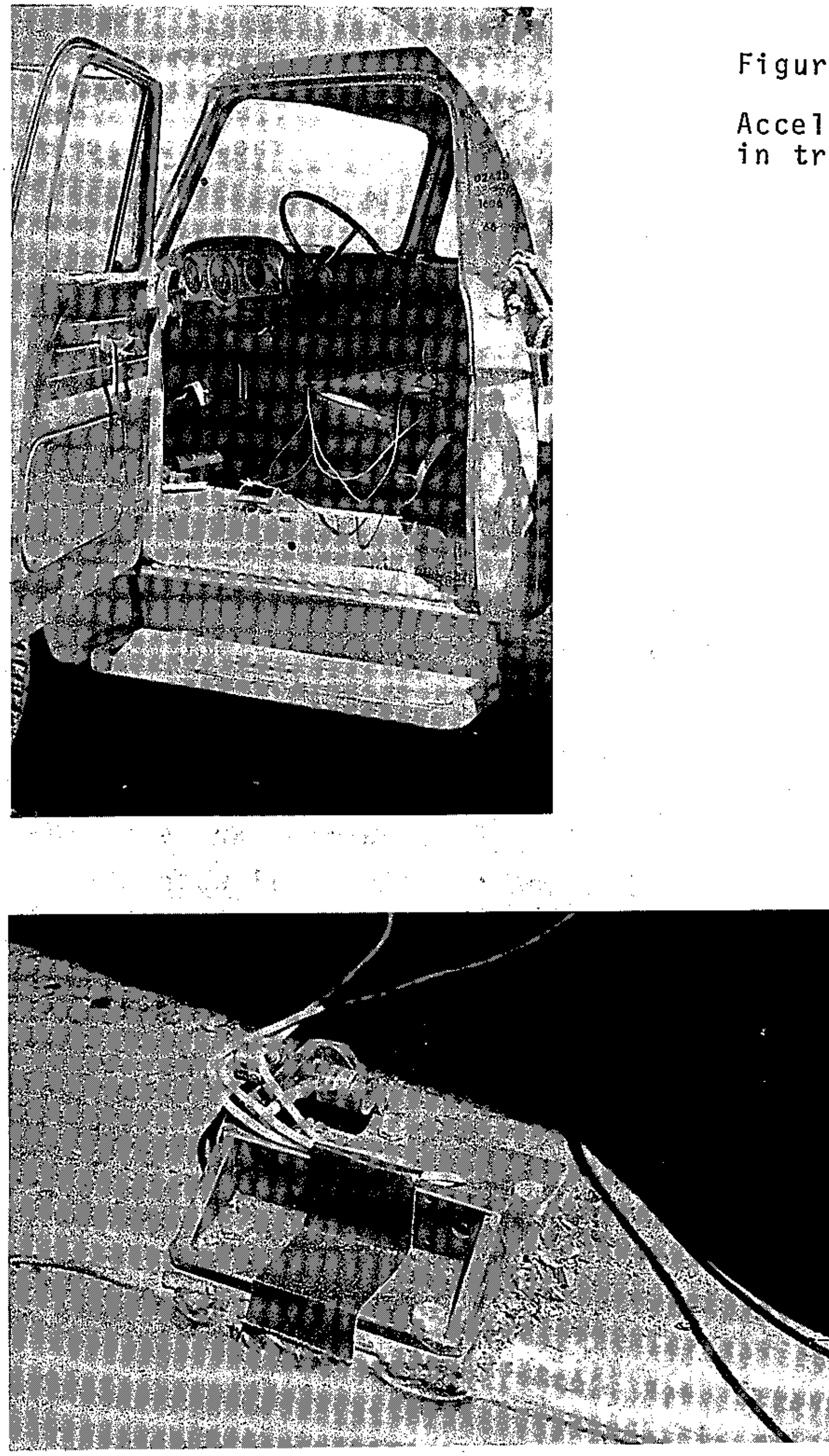


Figure C1.

Accelerometer mount bracket in truck cab.

After the test the tape recorder data was played back through a Visicorder which produced an oscillographic trace (line) on paper for each channel of the tape recorder. Each paper record contained a curve of data representing one accelerometer, signals from the three event marker tape switches and bumper impact tape switch, and time cycle markings.

Some of the accelerometer data records contained high frequency spikes. This data was filtered at 100 Hertz and 12 db with a Krohn-Hite filter to facilitate data reduction. The smoother resultant curves give a good representation of the overall acceleration of the vehicle without significantly altering the amplitude and time values of the acceleration pulses.

Accelerometer records from the car, truck, and dummy are shown in Figures C2-C13. The cross hatched areas on the accelerometer records show the time interval when the highest 50 ms. average values of acceleration occurred.

Figure C2, CAR AND TRUCK ACCELERATION VS TIME
TEST 371

Truck Mounted Attenuator

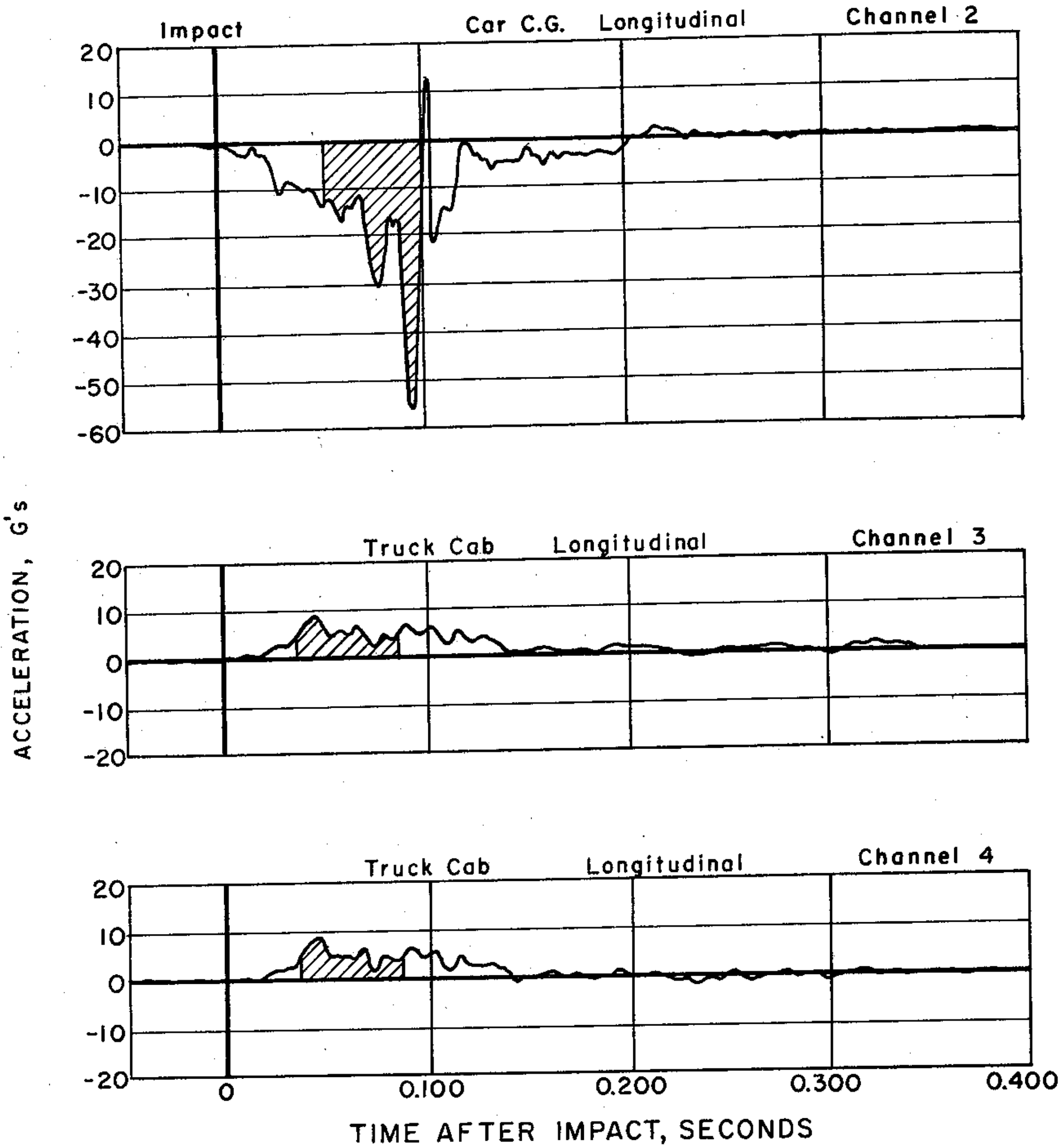


Figure C3, DUMMY ACCELERATION VS TIME
TEST 371
Truck Mounted Attenuator

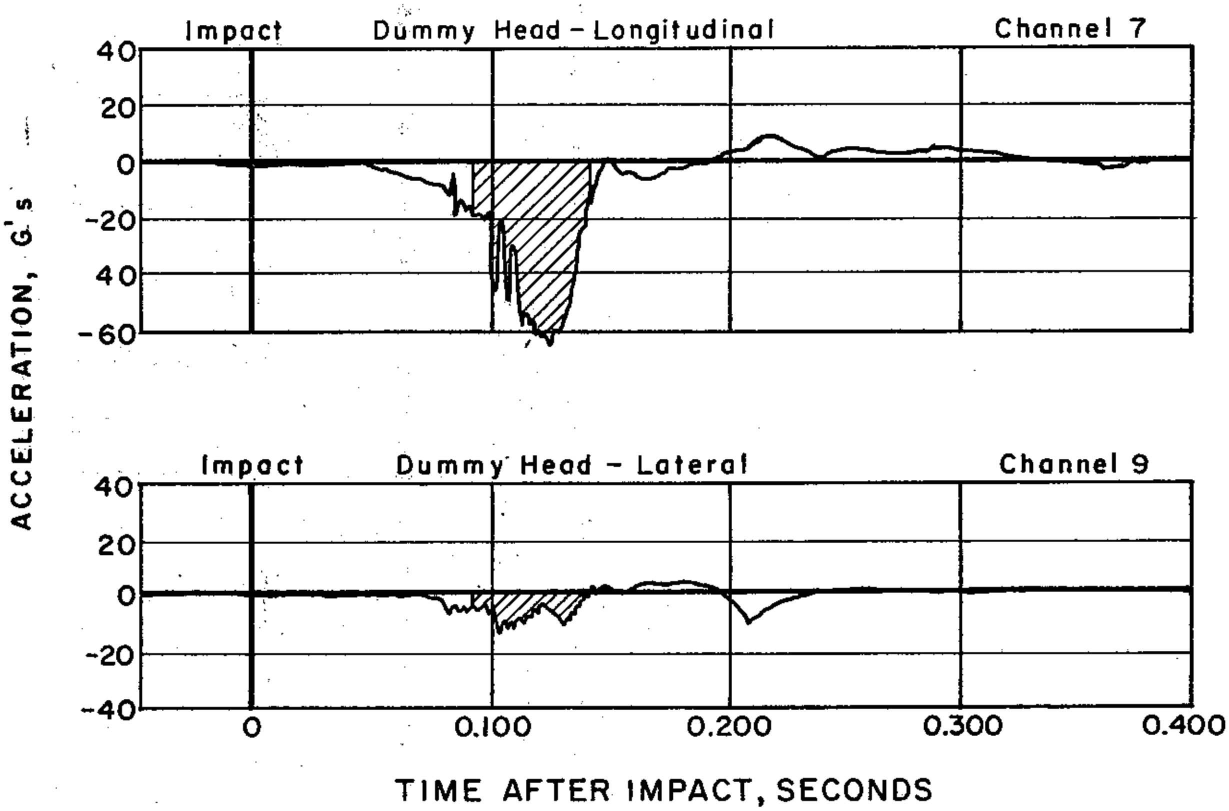


Figure C4, CAR AND TRUCK ACCELERATION VS TIME
TEST 372
Truck Mounted Attenuator

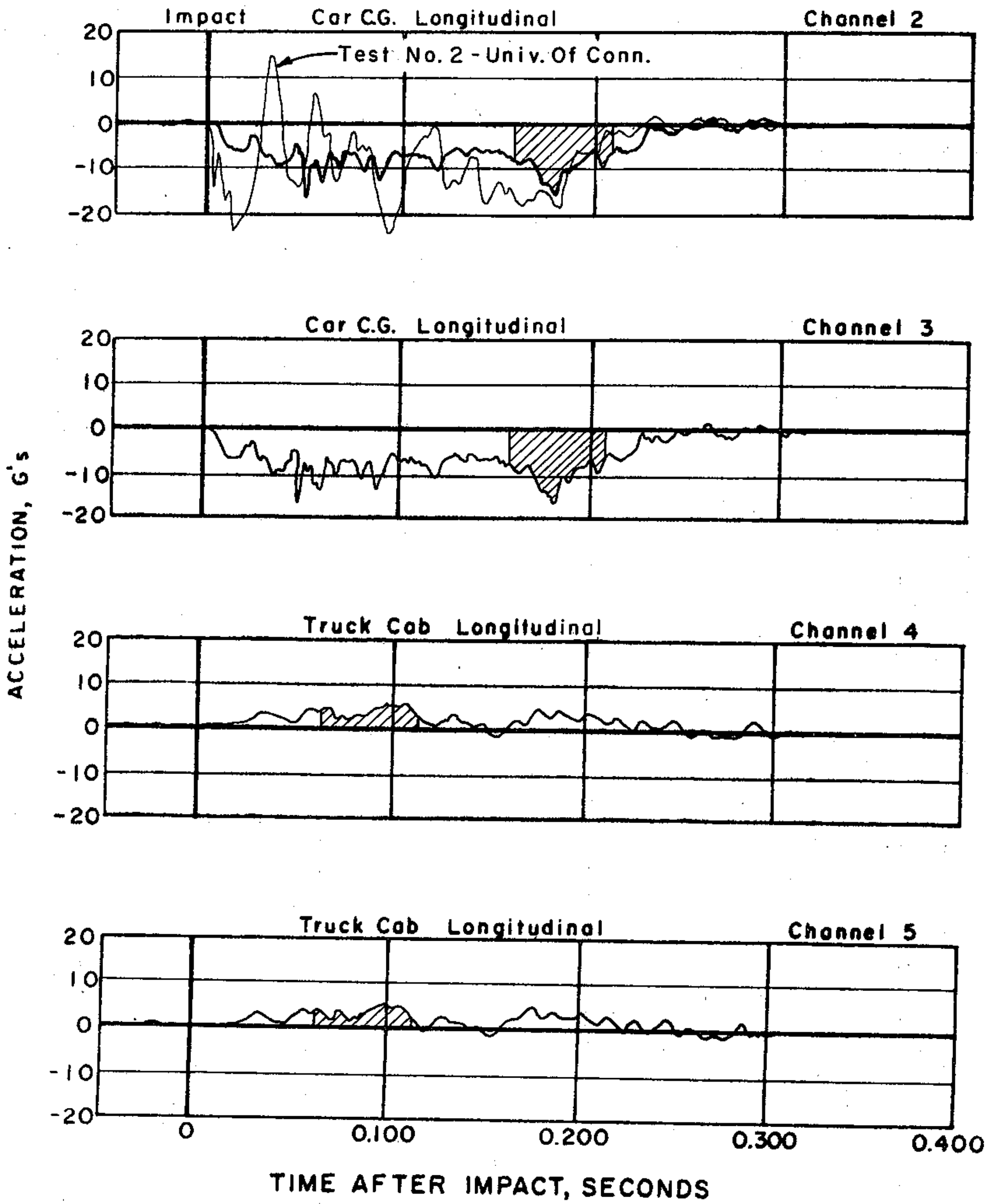


Figure C5, CAR AND DUMMY ACCELERATION VS TIME
TEST 372
Truck Mounted Attenuator

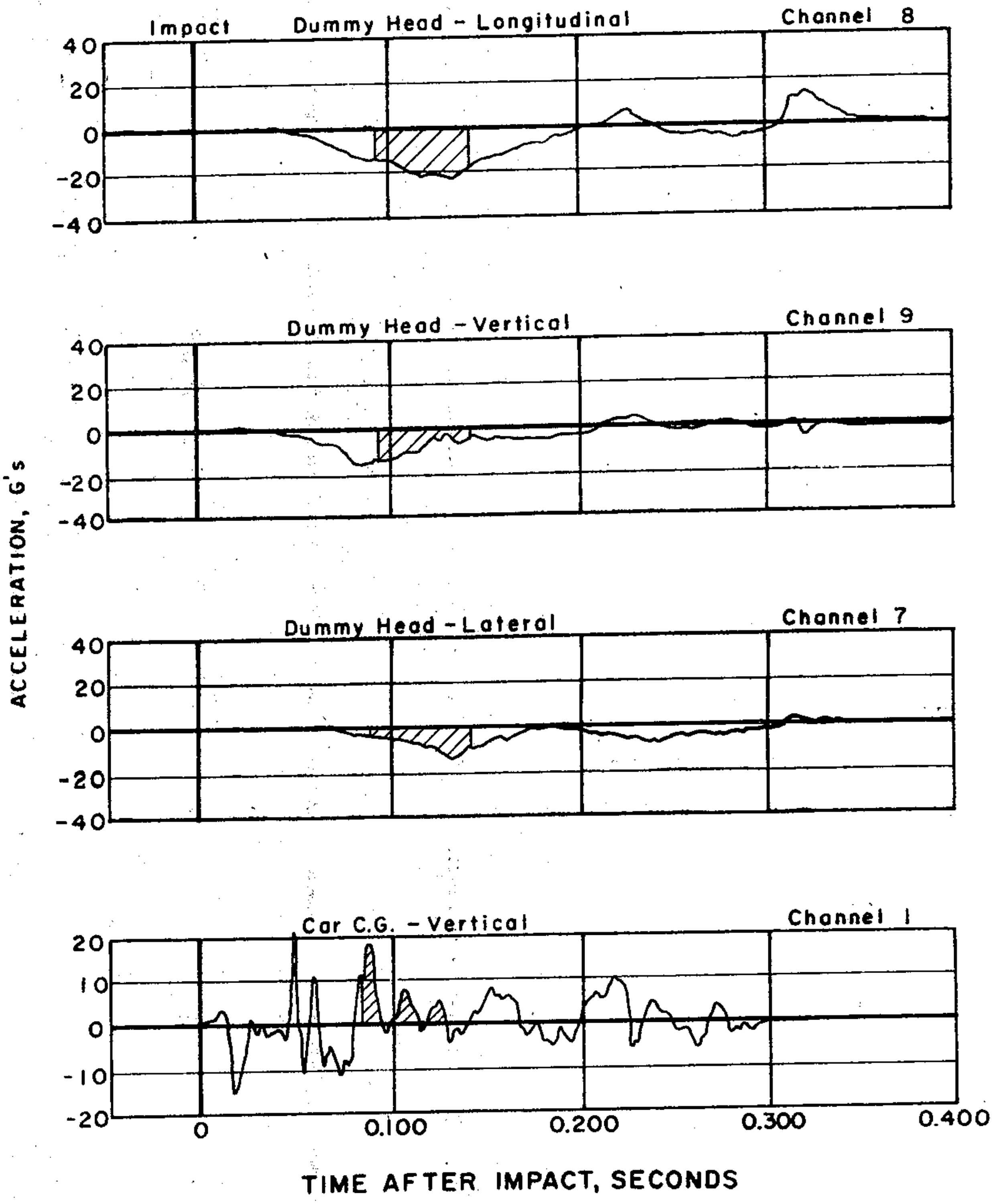


Figure C6, CAR AND TRUCK ACCELERATION VS TIME
TEST 373

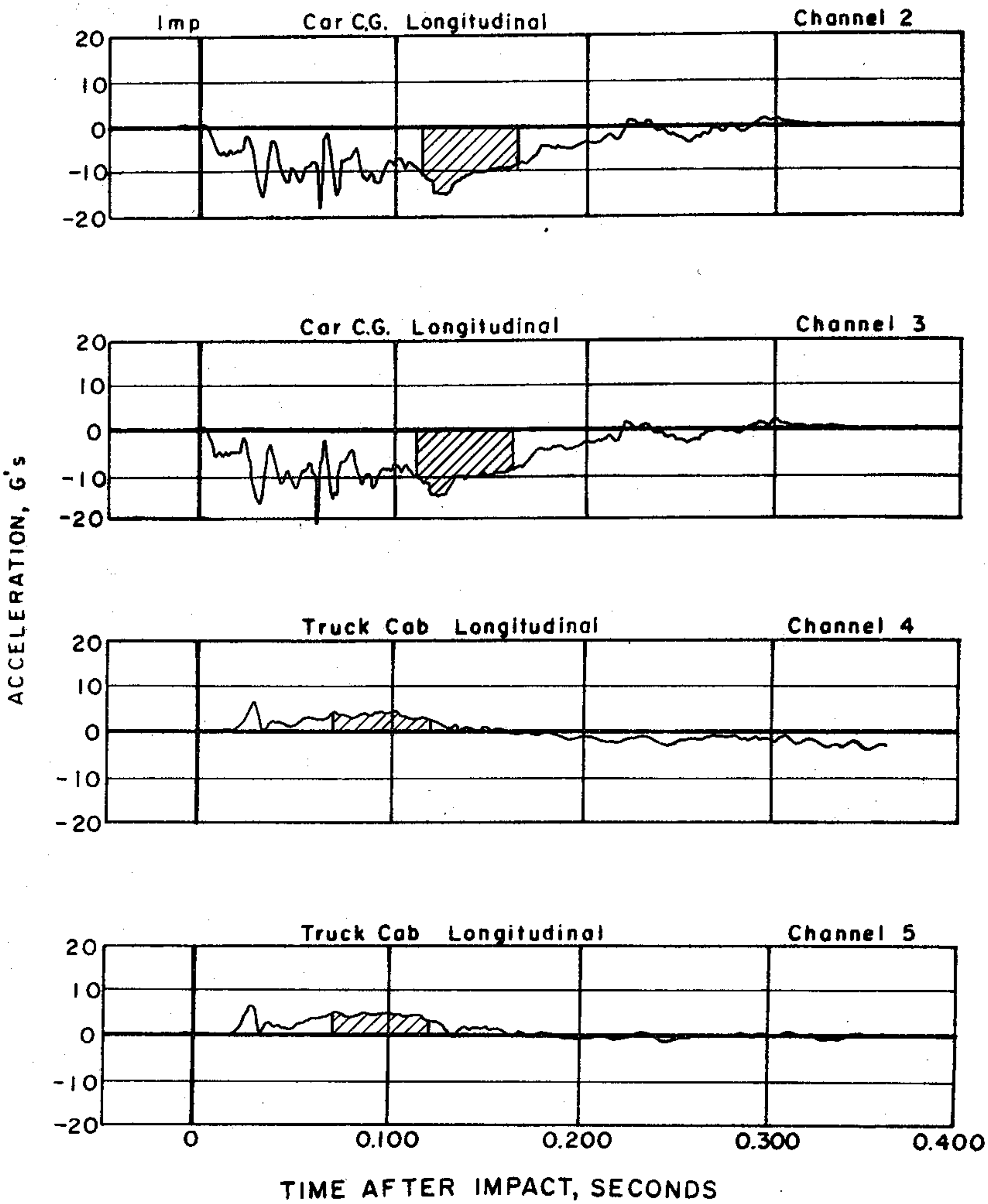


Figure C7, CAR AND DUMMY ACCELERATION VS TIME
TEST 373
Truck Mounted Attenuator

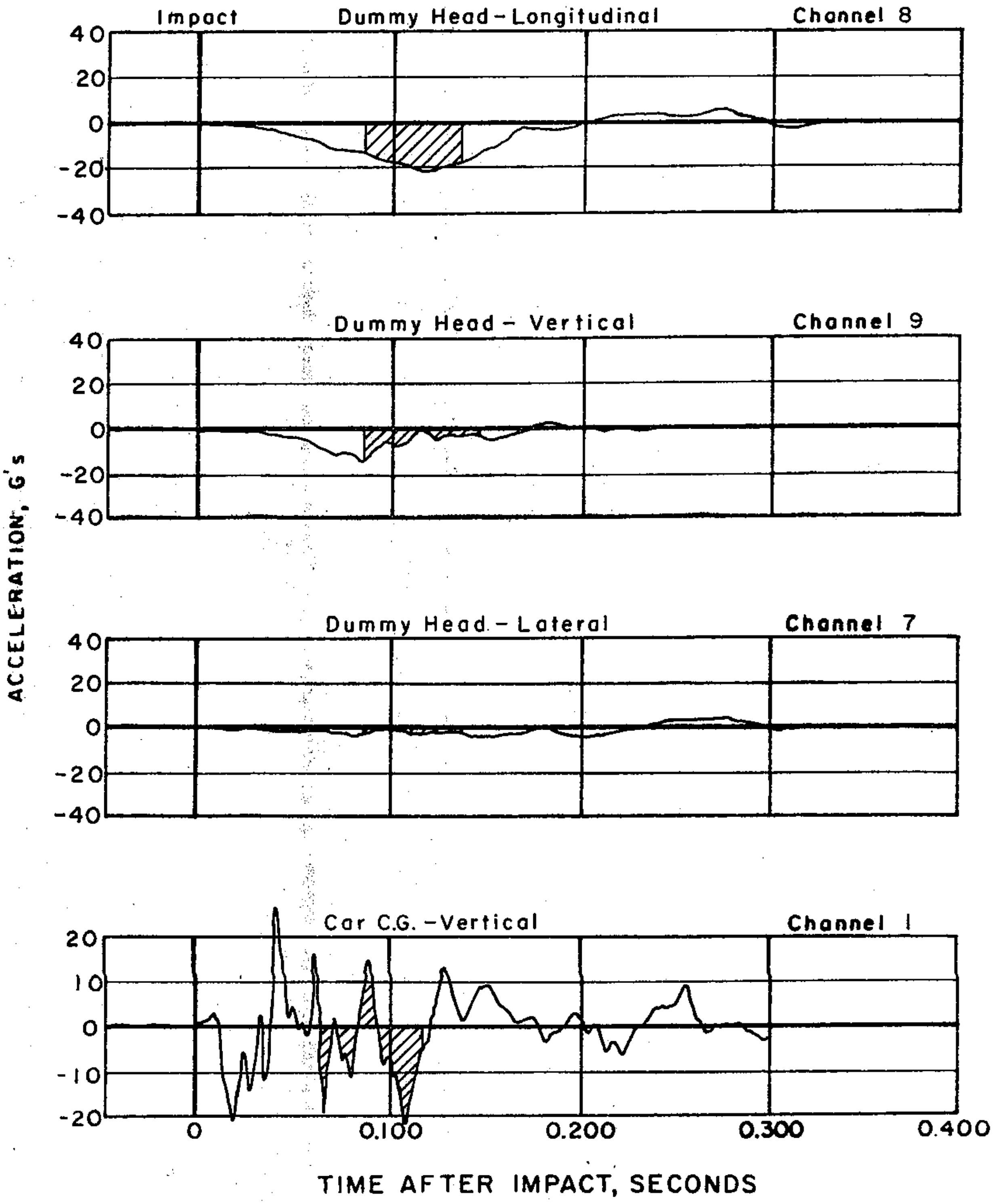


Figure C8, CAR AND TRUCK ACCELERATION VS TIME
TEST 374

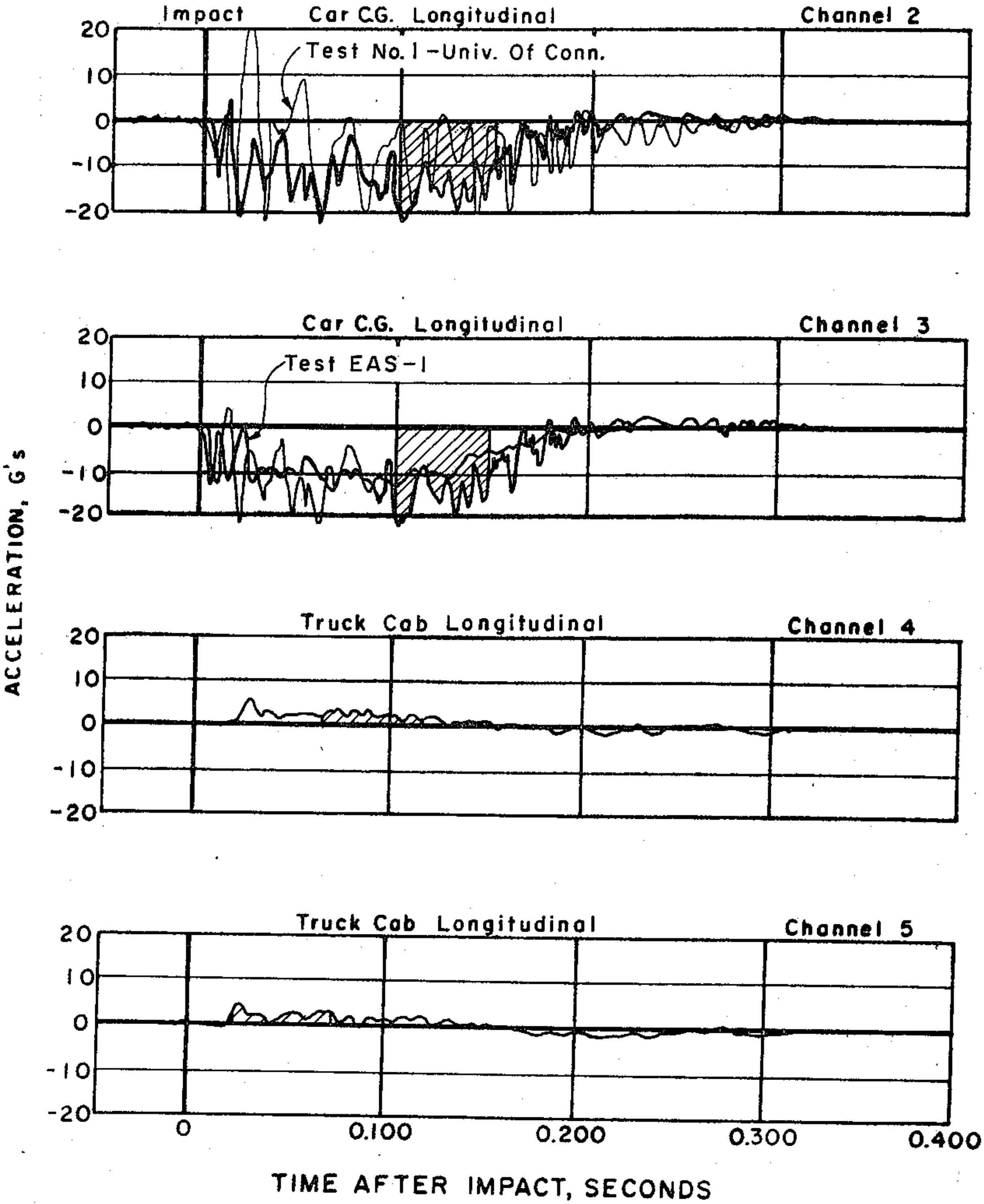


Figure C9, CAR AND DUMMY ACCELERATION VS TIME
TEST 374
Truck Mounted Attenuator

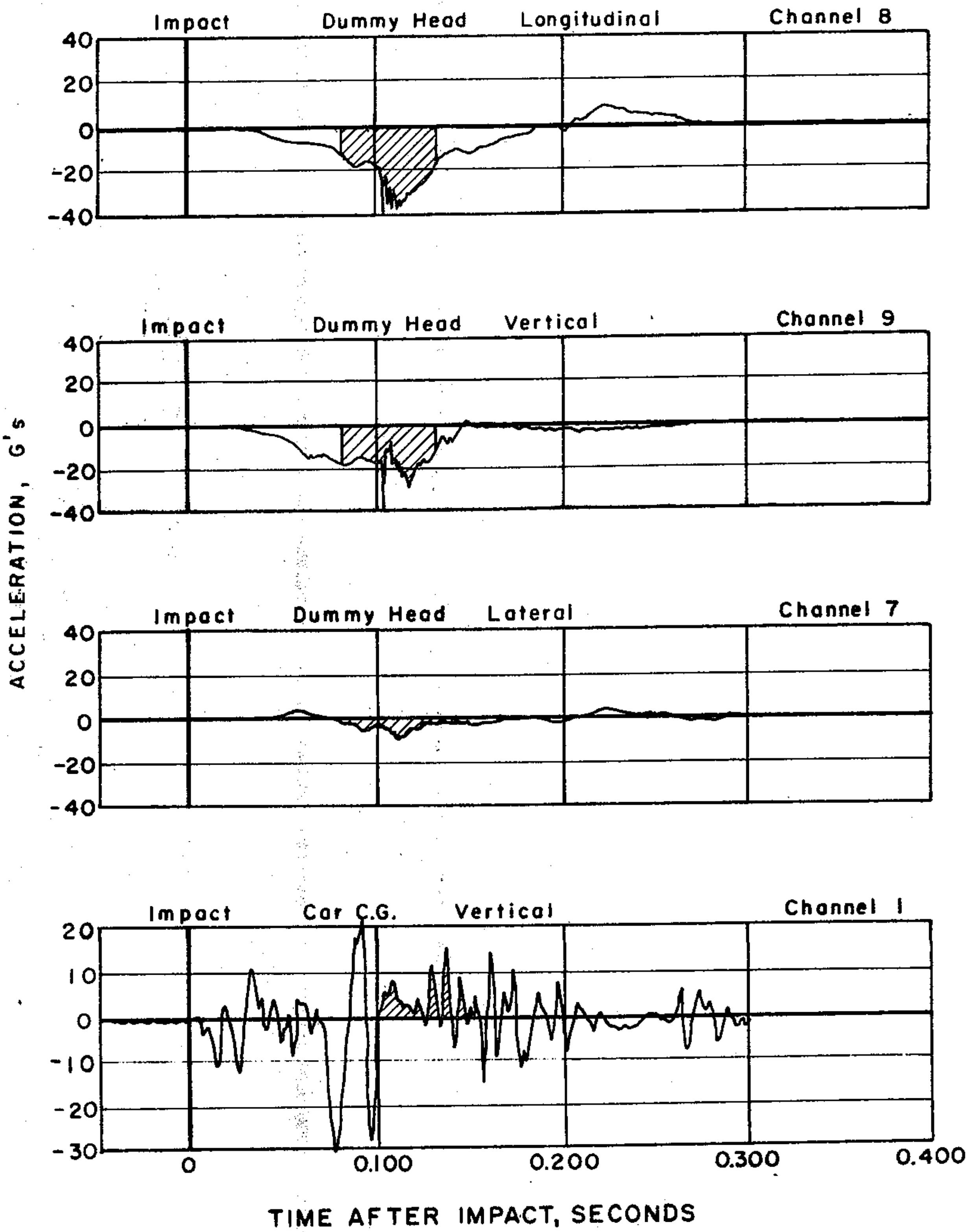


Figure C10, CAR AND TRUCK ACCELERATION VS TIME

TEST 375

Truck Mounted Attenuator

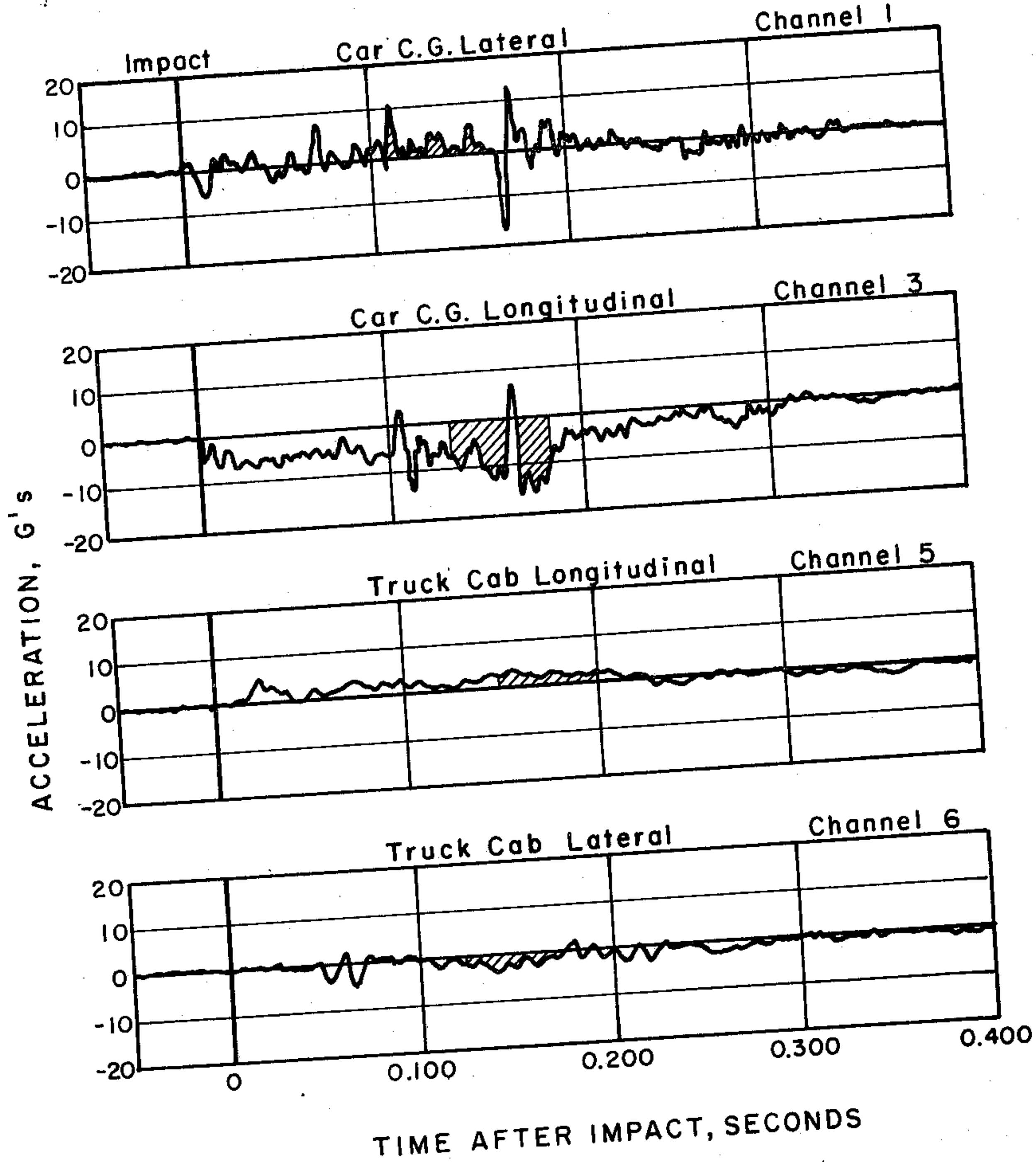


Figure CII, CAR AND DUMMY ACCELERATION VS TIME

TEST 375

Truck Mounted Attenuator

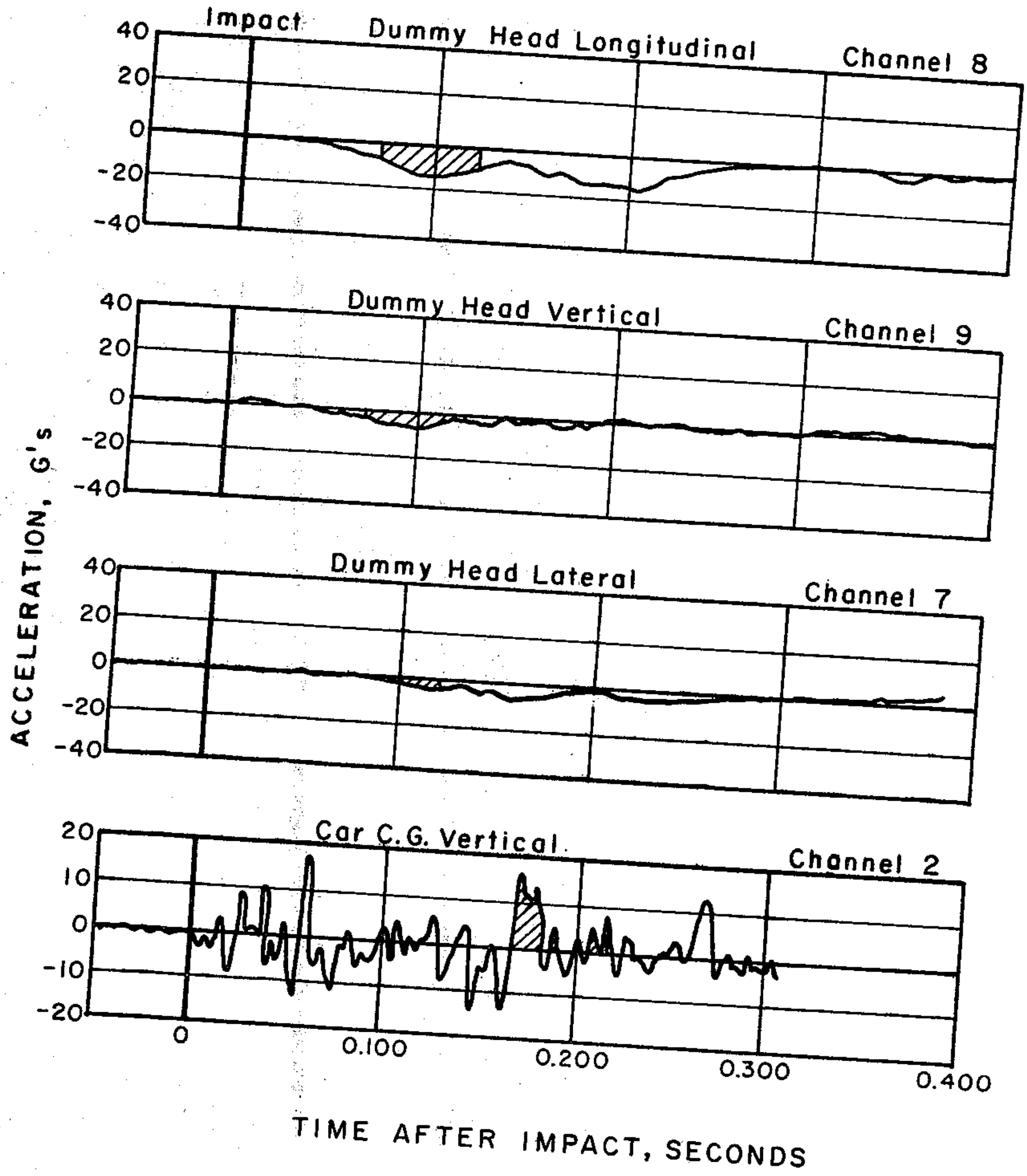


Figure C12, CAR AND TRUCK ACCELERATION VS TIME

TEST 376

Truck Mounted Attenuator

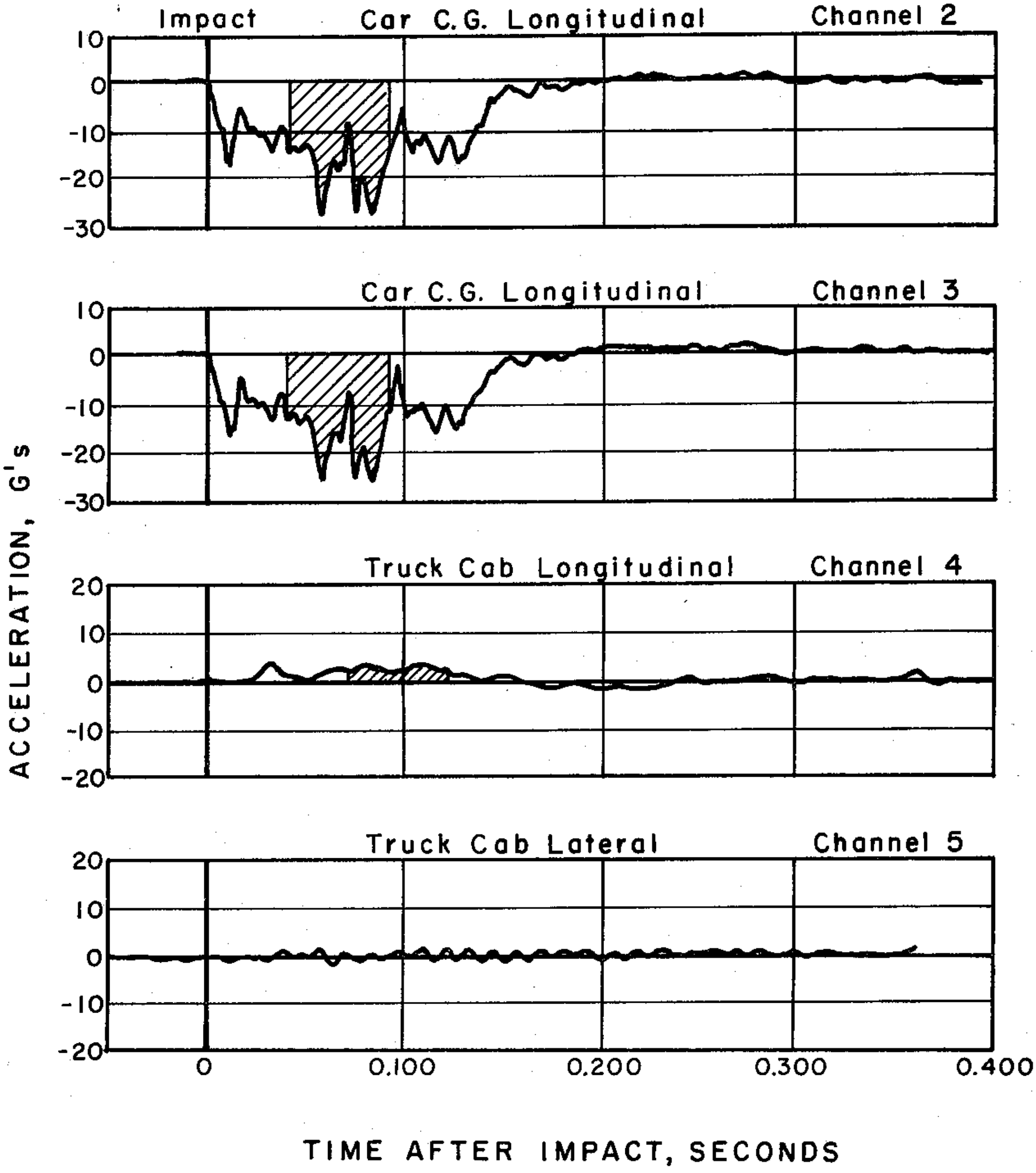
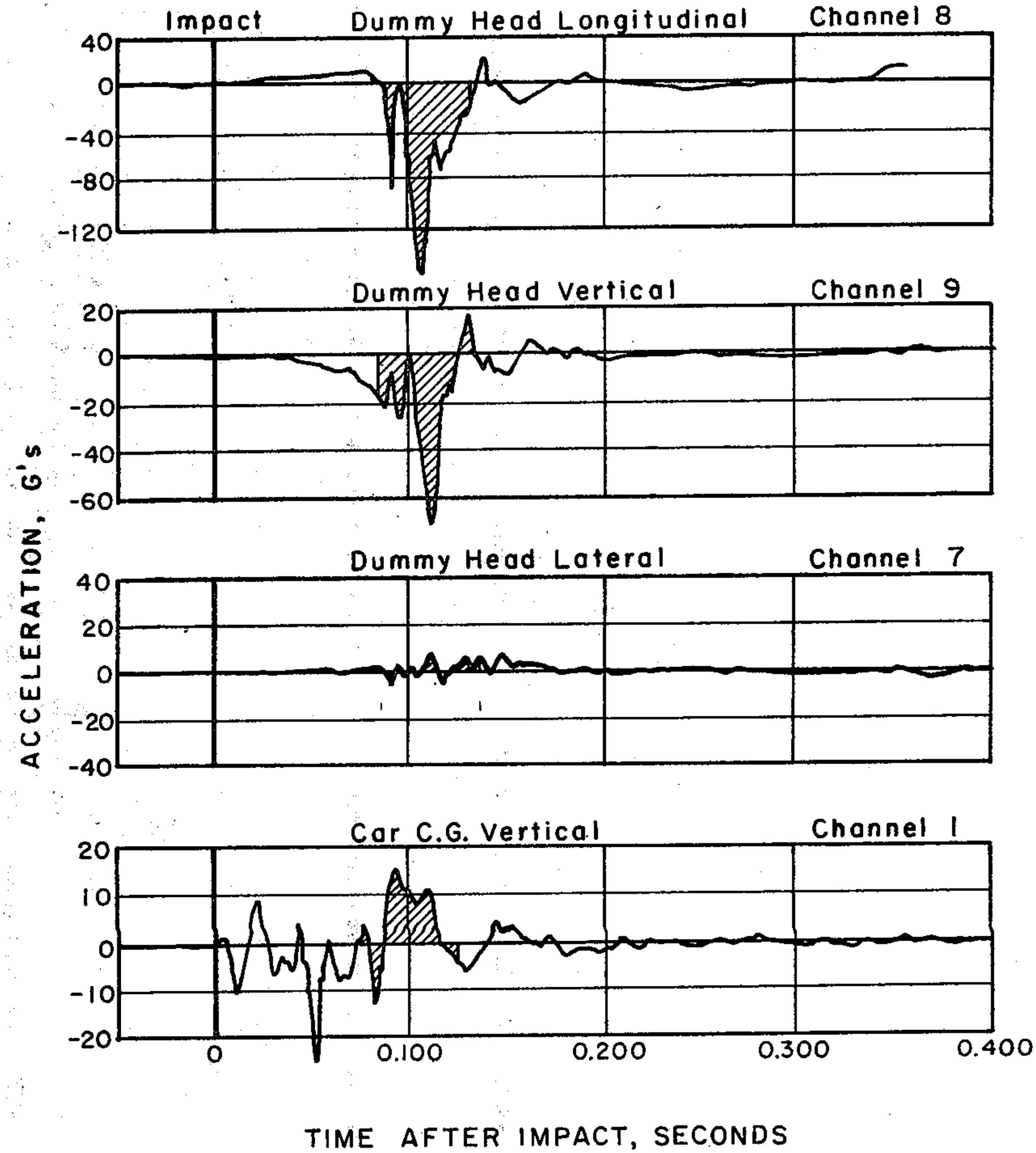


Figure C13, CAR AND DUMMY ACCELERATION VS TIME
TEST 376
Truck Mounted Attenuator

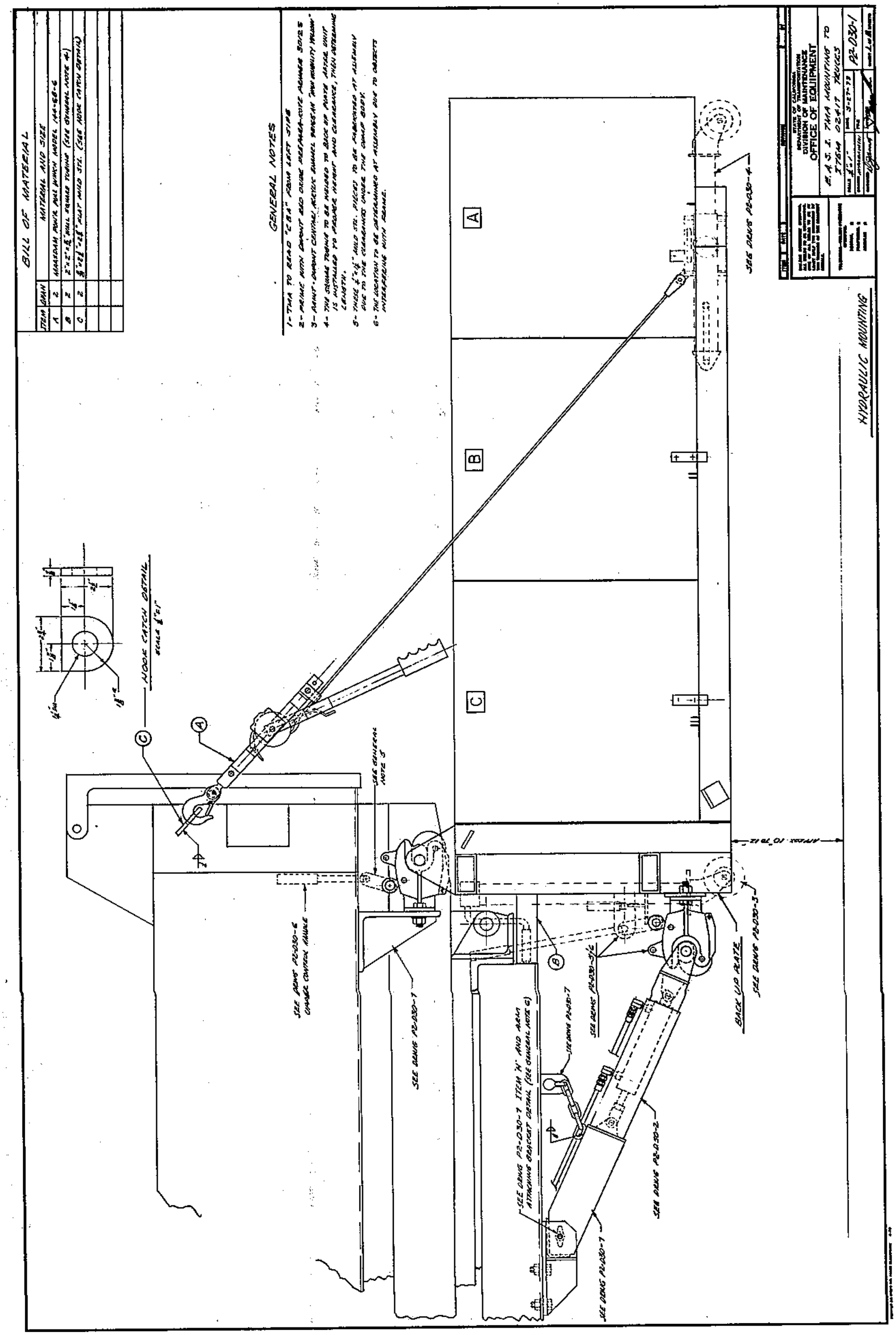


APPENDIX D: Truck Mounted Attenuator Plans and Details

Figures D1 through D8 are the engineering drawings for the Caltrans supplied hardware used to mount a TMA on a dump truck. These were the contract drawings finalized after all crash tests were completed and used to purchase the hardware.

The Caltrans Office of Equipment will assemble this hardware and use it to mount 80 operational TMA's that were purchased recently.

Figure D1, TMA Attachment Hardware Details



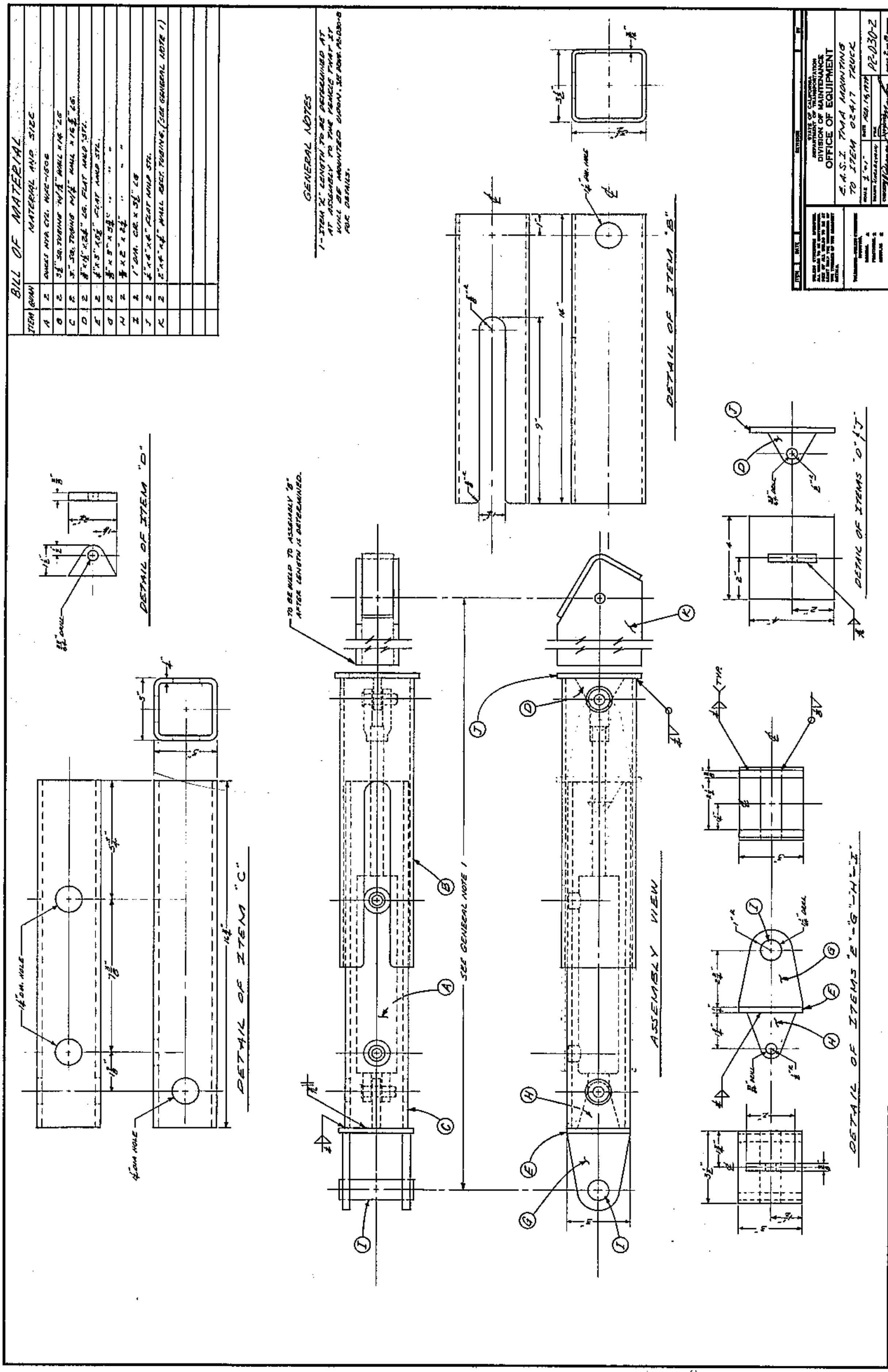
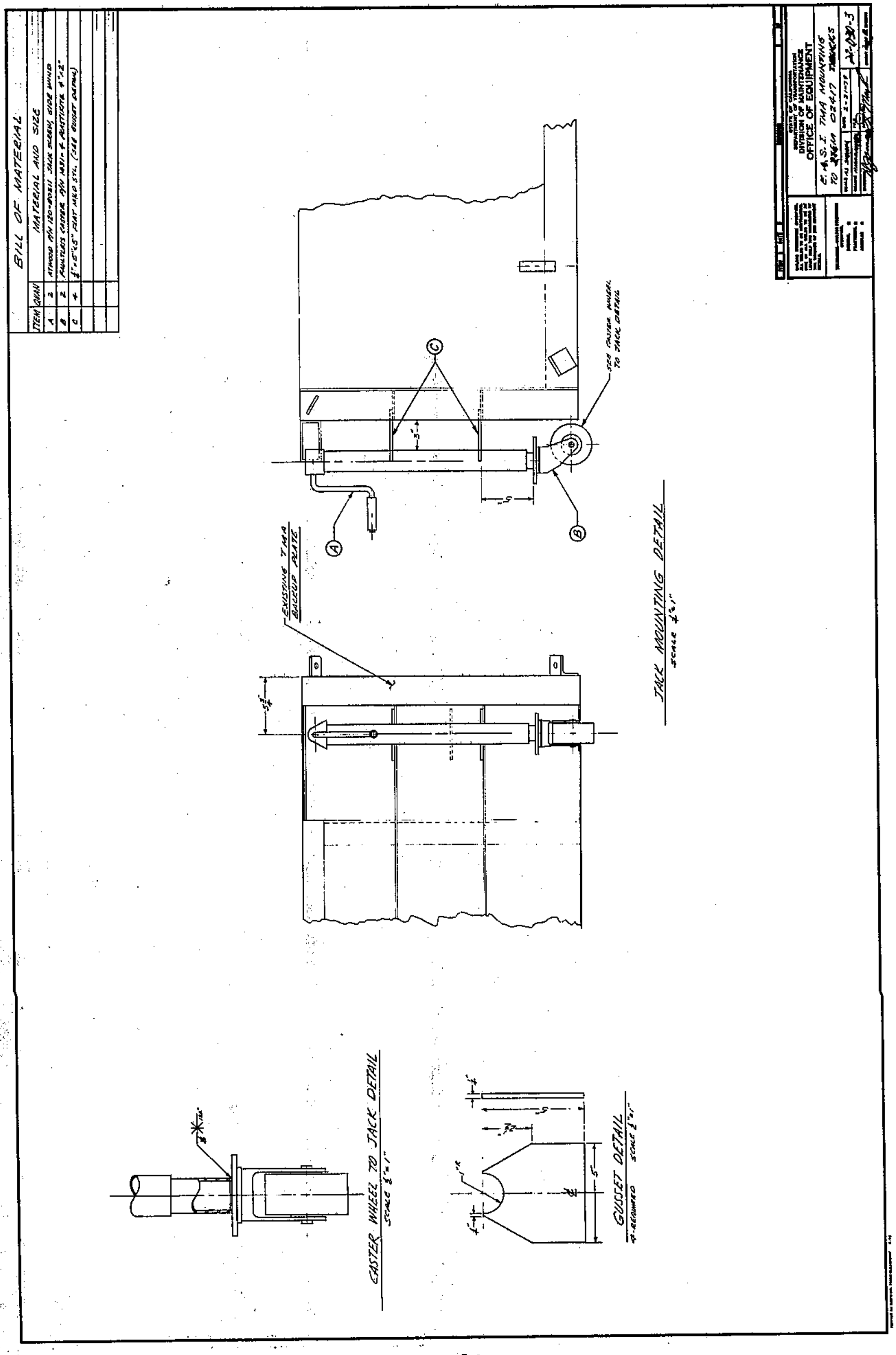

BILL OF MATERIAL
ITEM
QUAN
MATERIAL AND SIZE
GENERAL NOTES
DETAIL OF ITEM "D"
DETAIL OF ITEM "C"
DETAIL OF ITEM "B"
SEE GENERAL NOTE 1
ASSEMBLY VIEW
DETAIL OF ITEMS "D"-"J"
DETAIL OF ITEMS "E"-"G"-"H"-"I"
STATE OF CALIFORNIA
DIVISION OF MAINTENANCE
OFFICE OF EQUIPMENT
E.A.S.I. TMA MOUNTING
TO ITEM 02417 TRUCK
P2-030-2

Figure D3, TMA Attachment Hardware Details



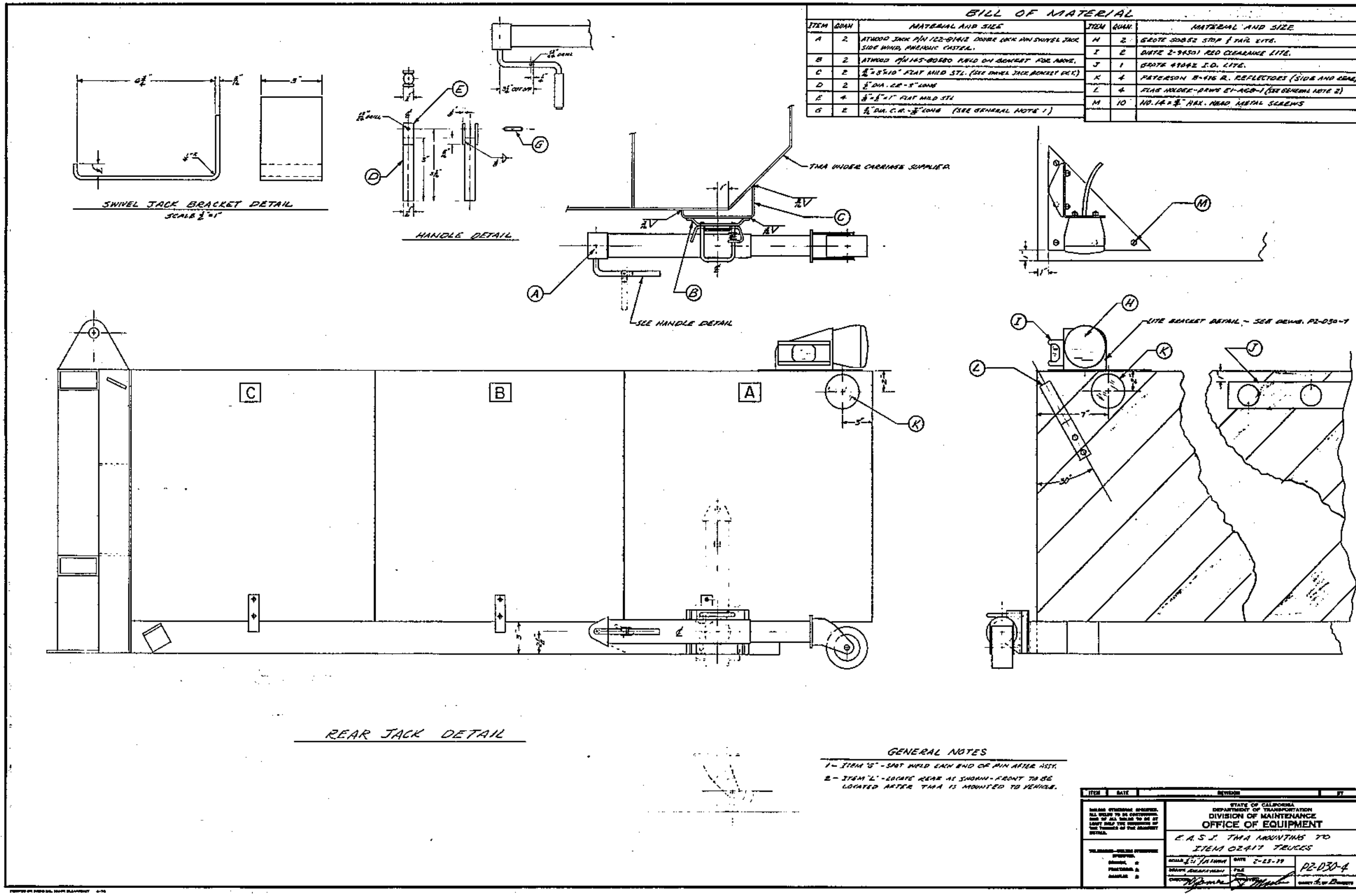

BILL OF MATERIAL
ITEM QUAN MATERIAL AND SIZE
A 2 ATWOOD JACK P/N 122-81412 DOUBLE LOCK PIN SWIVEL JACK SIDE WIND, PHENOLIC CASTER.
B 2 ATWOOD P/N 145-80580 WELD ON BRACKET FOR ABOVE.
C 2 FLAT MILD STL. (SEE SWIVEL JACK BRACKET DET.)
D 2 DIA. C.R. - 5" LONG
E 4 FLAT MILD STL
G 2 DIA. C.R. (SEE GENERAL NOTE 1)
H 2 GROTE 50852 STOP & TAIL LITE.
I 2 DIETZ 2-94501 RED CLEARANCE LITE.
J 1 GROTE 49042 I.D. LITE.
K 4 PETERSON B-476 R. REFLECTORS (SIDE AND REAR)
L 4 FLAG HOLDER - DRWG E1-AGB-1 (SEE GENERAL NOTE 2)
M 10 NO. 14 HEX. HEAD METAL SCREWS
SWIVEL JACK BRACKET DETAIL
HANDLE DETAIL
TMA UNDER CARRIAGE SUPPLIED
SEE HANDLE DETAIL
LITE BRACKET DETAIL - SEE DRWG. P2-030-7
REAR JACK DETAIL
GENERAL NOTES
1 - ITEM "G" - SPOT WELD EACH END OF PIN AFTER ASSY.
2 - ITEM "L" - LOCATE REAR AS SHOWN - FRONT TO BE LOCATED AFTER TMA IS MOUNTED TO VEHICLE.
STATE OF CALIFORNIA
DEPARTMENT OF TRANSPORTATION
DIVISION OF MAINTENANCE
OFFICE OF EQUIPMENT
E.A.S.I. TMA MOUNTING TO ITEM 02417 TRUCKS
2-23-79
P2-030-4

Figure D5, TMA Attachment Hardware Details

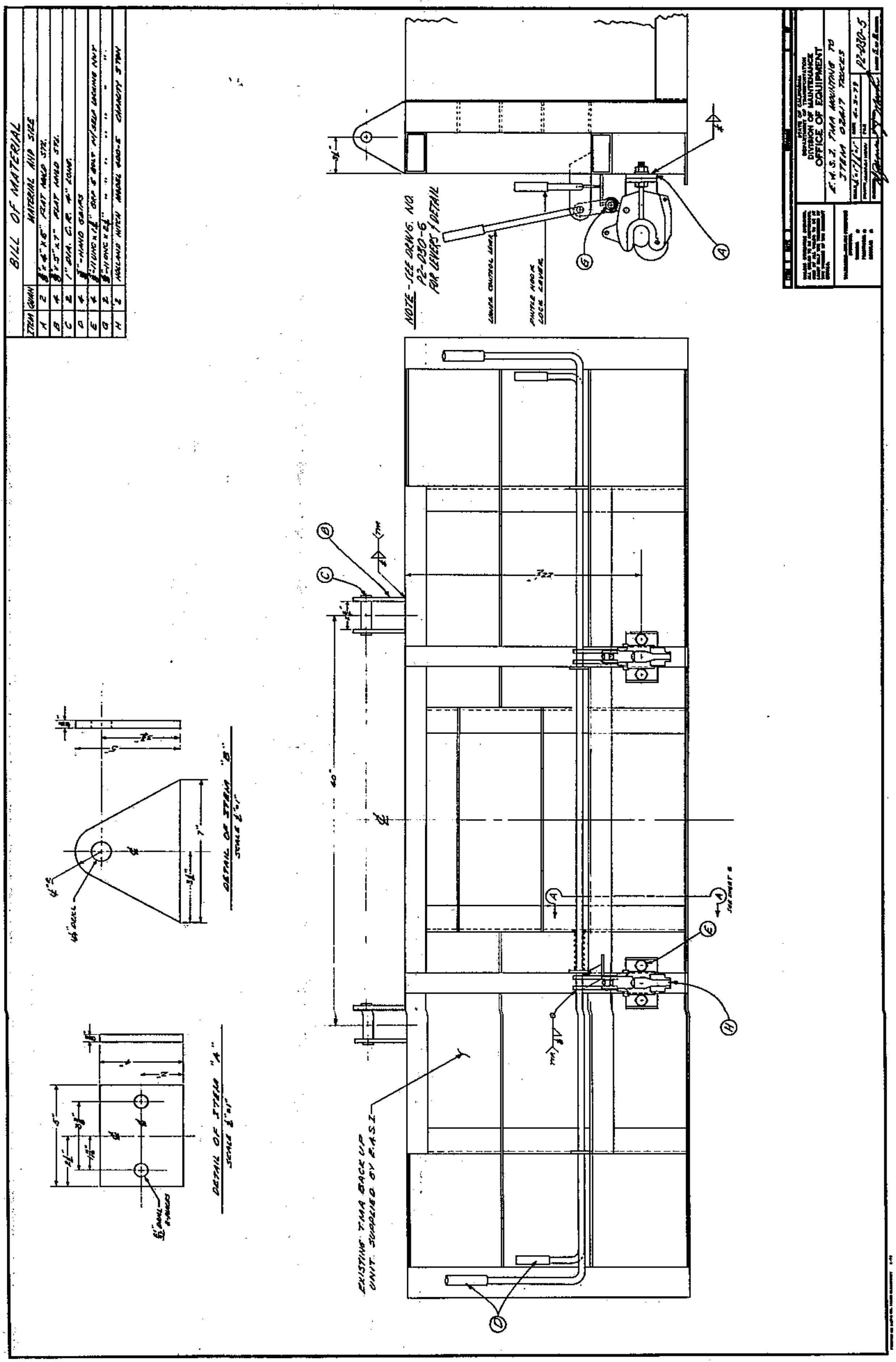


Figure D6, TMA Attachment Hardware Details

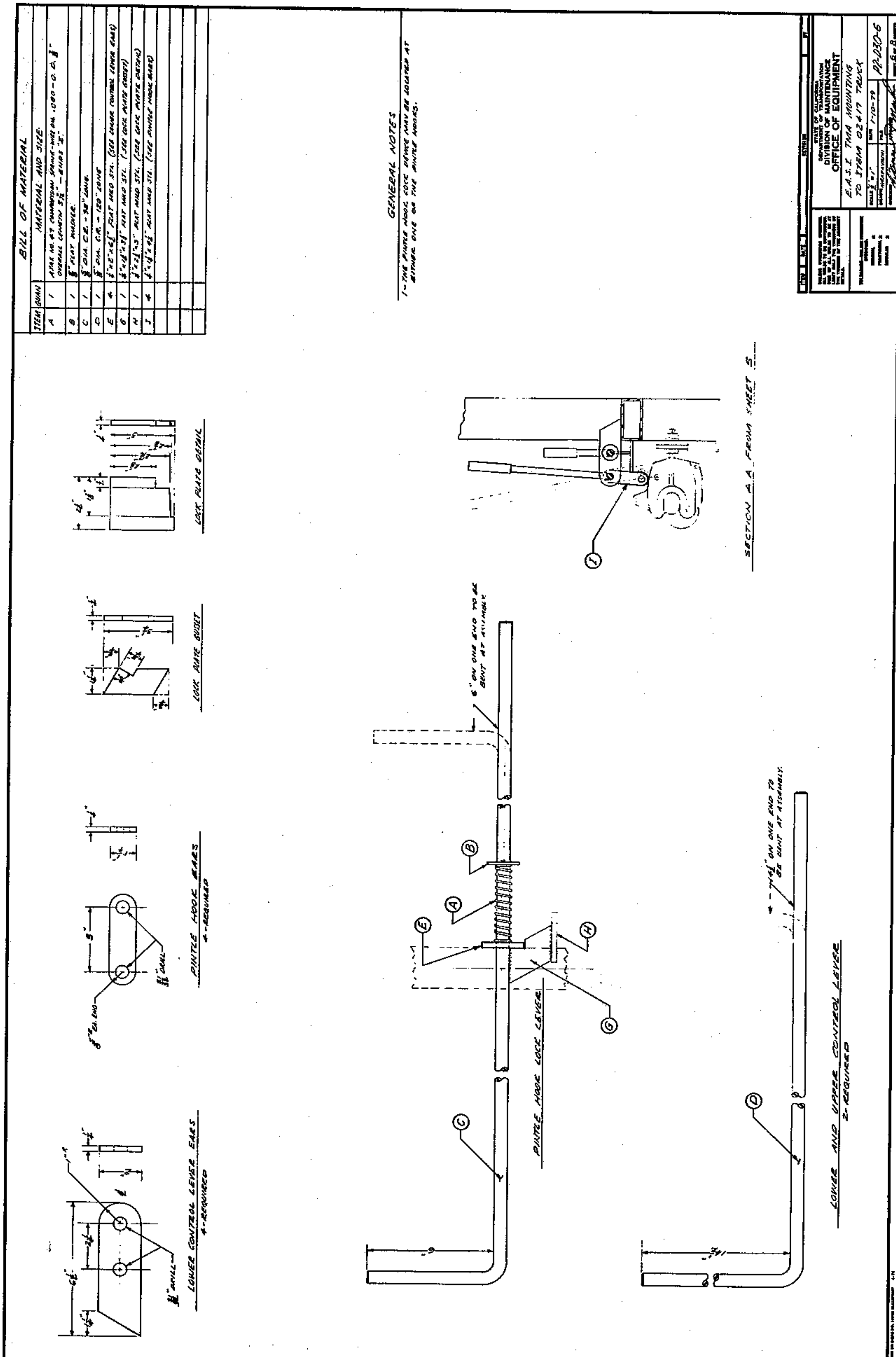


Figure D7, TMA Attachment Hardware Details

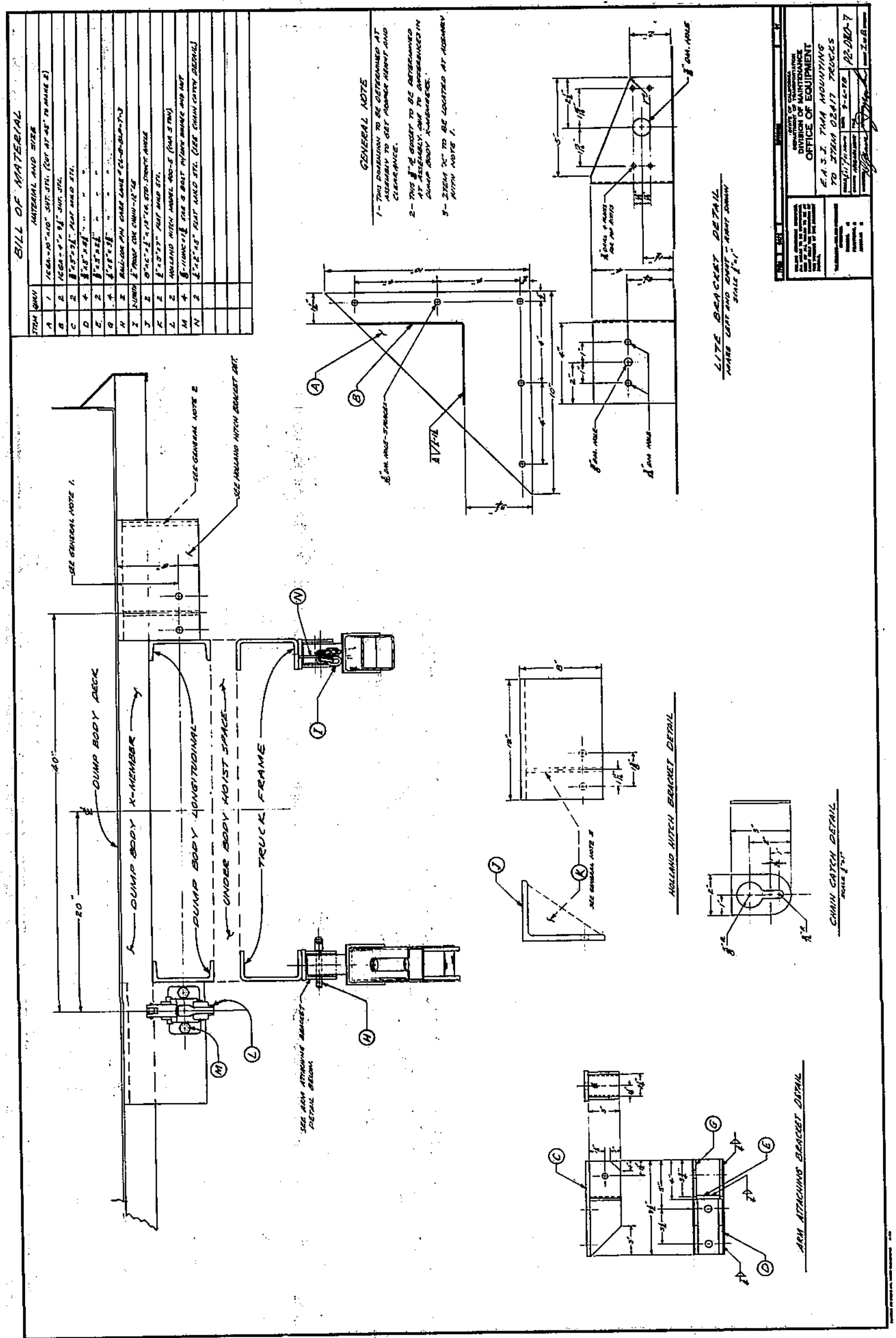
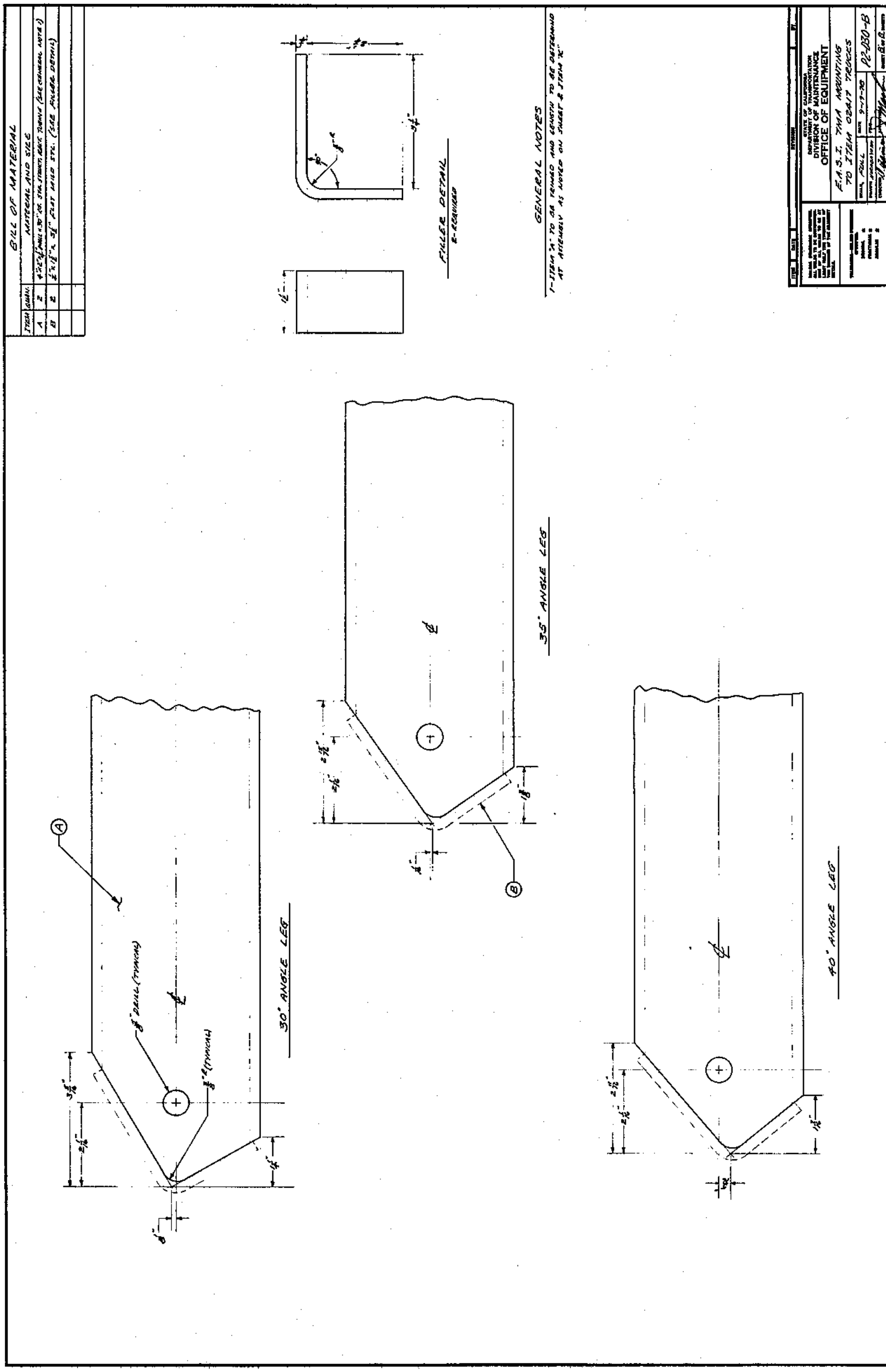


Figure D8, TMA Attachment Hardware Details



APPENDIX E: Accident Experience

Rear End Accidents Involving Caltrans Shadow Vehicles

Detailed data was tabulated on all impacts into Caltrans shadow vehicles in 1978. The data was taken from accident records, with added data from the districts, and compiled by the Departmental Safety Branch in the Caltrans Division of Administrative Services. Table E.1 condenses some of that information for all rear end impacts. The purpose of the condensed table is to show typical impact speeds, size of State and private vehicles, whether or not the Caltrans vehicle was parked, vehicle damage, and number of injury accidents. That data is analyzed in Table E.2.

It can be concluded from the data in Table E.2 that we can expect State trucks equipped with TMA's to be impacted not only by passenger cars traveling under 45 mph, but also by cars traveling faster and by heavy vehicles. Therefore, in a certain percentage of impacts the capacity of the TMA will be exceeded. Nevertheless, even in these more severe impacts, the TMA should provide some reduction in the car acceleration as compared with the case of a truck without a TMA. The data also show that three-fourths of the Caltrans vehicles that were impacted were parked.

Rear End Accidents Involving Caltrans Trucks Mounted With TMA's

As of March 1980 the Office of Equipment reported that four TMA's had been in service 1 1/2 years and seven TMA's had been in service 1/2-1 years. Only three accidents

TABLE E.1 SUMMARY OF REAR END IMPACTS INTO CALTRANS SHADOW VEHICLES - 1978

		PRIVATE VEHICLE				STATE VEHICLE		
No.	Est. Speed	Type	Damage	Injuries[1]	Location[2]	Type	Damage	Injuries[1]
1	?	'75 Peterbilt Tractor and Semi-trailer	Left front side, right side	N	P	'72 Intern'l 4-Yd Dump	Complete left rear corner	N
2	?	Passenger Sedan	Grille, radiator hood	N	P	Truck	None	N
3	45-55	'69 Ford LTD Station Wagon	Front end	F	M,O	'69 Ford 2-tn Dump Bed	Ret. rear spring, diff. moved, drive-line, trans. broken, tool box broken, frame	I
4	65-70	'77 Dodge Van	Front	I	M,O	'75 Dodge 3/4 ton pickup	Totaled	I
5	25	'76 Ford Panel	Two bolts broken on right rear view mirror	N	P	'71 Dodge Util. Body	Left rearview mirror broken, left rear amber light ring twisted	N
6	10-15	'68 Ford LTD Sta. Wagon	Sheet metal damage to left front fen-der, hood, grill	N	P,O	'72 Ford Truck Hot Striper	None	N
7	35	'74 Chev. 2-dr. Sedan	Pulled off chrome strip from rt. side	N	P	'71 Intern'l 3-Yd Dmp.Trk.	Scratch on left fender	N
8	?	Chev. Sta-tion Wagon	Left front fender and headlights	N	P,O	'72 Intern'l 2-Tn Dump	Tore off right hand mud flap	N
9	?	'68 Mercury 2 dr Cougar	Front end	N	P	(Early Warn-er) Tlr.Mtd.	Unknown	N

		PRIVATE VEHICLE				STATE VEHICLE		
No.	Est. Speed	Type	Damage	Inju-ries[1]	Loca-tion[2]	Type	Damage	Inju-ries[1]
10	55	Volkswagen 2 Dr.Sta.Wag.	Front end	I	M,O	'71 Intern'l 1 Ton Lift Gate	Hydrolifts damaged, mounting brackets for lift gate broken, spring shackles broken	I
11	?	'74 2-dr. Chevrolet	Front end	I	P	Intern'l Pickup	Rear axle, pickup bed rear, cab, transmission	N
12	50	'76 Ford Pickup	Front end	N	M,O	'72 Dodge Pickup	Totaled	I
13	?	'71 Peter-bilt	None	N	P	'67 Ford 2-Tn Cab-over	Lt. rear amber light shattered, 3 braces supporting left side-boards broken, left mirror shattered, left directional light broken	N
14	?	Diesel Trac-tor	Unknown	N	P	'75 Intern'l D.P. 4-Yd.	Left mirror, left tip of plow	N
15	25	'69 Chev.	Right front fender, headlight, grille	N	P	'69 Ford CCHAF80	None	N
16	?	'53 Pickup	Left front fender and side	N	P	'75 Ford Butler Loader	None	N
17	?	'76 Corolla 2 Dr. Sedan	Totaled front end	N	M,O	'69 Intern'l 2-T Cargo Trk.	2 Traillight, 2 backup lights, tlr. hitch, license plate and lights, steps	N
18	?	Unknown	Unknown	N	P	'71 Dodge 3/4 T.Pickup	Dent on left side, back of driver's door	N

2

		PRIVATE VEHICLE				STATE VEHICLE		
No.	Est. Speed	Type	Damage	Inju-ries[1]	Loca-tion[2]	Type	Damage	Inju-ries[1]
19	?	'70 Ford Super Van	Extensive damage to front	I	P	'71 Intern'l 1-T Trash	Bent frame, other extensive damage	F
20	?	Kenworth Trac/trailer	Rear trailer was overturned; damage unknown	N	P	'69 Ford 1-T Dump Bed	Dump body, lt. rear taillight, lt. side of utility boxes, lt. back cab, rt. front bumper and fender	N
21	20-30	'66 Intern'l Trac/trlr	Rear corner	N	P	'72 Ford CCHA	Lt. rear corner of bed and clearance lamp	N
22	50	'76 Olds 2-dr. Cutlass Supr.	Crushed front end (rt. side), roof, windshield front and rear	I	P	'73 Dodge 1-T Cargo	Left rear end	I
23	?	Unknown	Unknown	N	P	'70 Ford 5.4 Tons	Rearview mirror broken	N
24	?	'65 Plymouth Fury Sedan	Totaled	F,I	M,O	'71 Ford 4-T with Loader	Rear end, airbrake cans, axle, rear springs	I
25	?	Unknown	Unknown	N	P,O	'72 Dodge 1/2-T Pickup	Broken mirror on left side	N
26	4-10	'69 Ford Van	Right rear lower quarter panel	N	P,O	'72 Dodge Utility	None	N
27	45	Ford Stake-bed	None	N	P	'72 Ford 2-T Cargo	Broken right side rear view mirror	N

		PRIVATE VEHICLE				STATE VEHICLE		
No.	Est. Speed	Type	Damage	Injuries[1]	Location[2]	Type	Damage	Injuries
28	?	'76 Trailer-mobil (40' trailer)	Right trailer side	N	P	'73 Ford 4-T Dump Body w/ Loader	Bent left rear taillight	N
29	55	'72 Ford 2-Dr.	Front end - needed towing	N	P	Roto Quincy Compressor, tlr. mounted	Right rear fender and side panel; broke parts internally, leaking; damaged hitch crane handle	
30	50	'76 Chevrolet Step Van	Right front and side, bumper, broken rear hinge	N	P,O	'69 Dodge 3/4 Ton U.B.	Left side of bed, side doors, left side of rear, left taillight broken, rear bumper, left mirror and bracket broken	N
31	52	'67 Intern'l Truck-trailer	Left front bumper and fender	N	P	2-ton Dump	Totaled	F
32	?	Unknown	Unknown	N	P	'73 Dodge 3/4 Ton Utility	Broken left rear-view mirror	N
33	55	'78 Toyota Pickup	Totaled	N	P	'72 Dodge 1/2 Ton Pickup	Unknown	N
34	?	'67 Pontiac Sedan	Front end	N	M,O	'77 Chev. P.U.	Rear bumper	N
35	?	Chevrolet El Camino	Unknown	N	M,O	'77 Chev. 3/4 Ton Pickup	Right side of right bumper	N

PRIVATE VEHICLE					STATE VEHICLE			
No.	Est. Speed	Type	Damage	Injuries[1]	Location[2]	Type	Damage	Injuries[1]
36	30	'73 Earth Cat Scraper	None	N	P	'75 Intern'l Personnel Hoist	Broke mirror, bent support rod	N
37	?	71/74 3-axle Trac/2-axle semi trailer	None	N	M,O	'68 Topeka Mower	Left fender, rotating light post, transfer case brace, front motor	I
38	?	'74 VW Thing	Front end	N	P	'66 Ford 4-T Fence Repair	None	N
39	?	'69 Ford 2-Dr Sedan	Front end	N	P	'72 Dodge 3/4 Ton Pickup	Tailgate dock bumper, broken taillight lens	N
40	?	Passenger Sedan	Extensive overall	F	M,O	2-T Dump Trk	Extensive overall	I
41	25	'73 Ford Pinto Sedan	Right middle of taillight	N	P	'75 Dodge 3/4 Ton Pickup	Left rear corner	N
42	?	Tractor, two trailers	2nd trailer damaged	N	P	'72 4-Yd Dump	Left front fender, bumper, steel apron in rear, brakes, frames and suspension, axle and engine	N
43	?	Passenger Vehicle	Left front	I	M,O	3/4 Ton Pickup	Bed, frame, cab	I

1 - F=Fatal, I=Injury, N=No injuries

2 - M=Moving vehicle, P=Parked vehicle, O=Occupied vehicle

TABLE E.2 Analysis of Rear End Accident Data

General

No. of rear end impacts	43
No of other types of impacts	21
Total no. of impacts in to shadow vehicles	64

Private Vehicle (Striking Vehicle) - Rear End Impacts

Vehicle Size

No. of heavy vehicles (large trucks)		11
No. of lighter vehicles		32
Vans	4	
Station wagons	4	
Pickups, panel trucks	4	
Passenger cars	20	

Vehicle Speed

No. of impacts at 45 mph or more	10
No. of impacts under 45 mph	8
No. of impacts where speed was unknown	25

Impact Severity

*No. of fatal accidents	3
*No. of injury accidents	6
*No. of accidents where injury and damage to private vehicle were "none" or "unknown"	10
*No. of PDO accidents	24

State Vehicle (Struck Vehicle) - Rear End Impacts

Vehicle Size

No. of 1/2 and 3/4 ton trucks	13
No. of dump trucks	9
Other trucks and vehicles	21

Operator Exposure

No. of parked state vehicles - occupied	5
No. of parked state vehicles - unoccupied	27
No. of moving state vehicles - occupied	11

Impact Severity

**No. of fatal accidents	2
**No. of injury accidents	9
**No. of PDO accidents	24
**No. of accidents where injury and damage to state vehicle were "none" or "unknown"	8

*Refers only to private vehicles and their passengers
**Refers only to state vehicles and their passengers

involving the TMA's had been reported. One was a minor brush hit, and one was extremely severe due to impact by a large truck at high speed. In the latter accident the TMA was obviously of no benefit. The third accident was moderate in severity, but no details were available.

APPENDIX F: Head Restraints and Whiplash

The Office of Equipment became interested in the problems of whiplash to Caltrans truck drivers in this project. They have embarked on a program to design head restraints that will minimize the effects of whiplash caused by rear-end impacts. This is part of an overall program to improve the safety of Caltrans personnel working on or near highways. The problem of whiplash was highlighted in Test 374 when the head of a dummy in the truck cab snapped back and broke the rear window. The use of head restraints would complement the use of TMA's to improve the safety of Caltrans truck operators.

At the request of the Office of Equipment, the researchers reviewed several technical papers on head restraints and whiplash. They are listed at the end of this appendix. It was concluded from the review that the analysis of the problem and the solutions to it were complex and somewhat elusive for the following reasons:

1. The human anatomy of the head and neck is extremely complex and impossible to duplicate exactly with dummies, primates, or computer programs. Human volunteers can be used only at low impact speeds. Testing by the use of any of the above methods is very expensive and time-consuming, even for a small number of tests.

2. It is very difficult, time-consuming, and expensive to do good accident studies on the effectiveness of head restraints. Police accident reports do not provide the necessary data; hence, researchers must do much legwork. The problem is compounded by the fact that the symptoms

of whiplash sometimes do not appear until days, weeks, or even months after the accident. Furthermore, the symptoms are often not measurable or discreet like a broken limb. In addition, it is difficult to estimate the impact speed and other impact conditions such as seating position or posture after the accident has occurred.

3. There is a great variation in injury propensity governed by the sex, age, weight, physical condition, amount of muscle tensing at impact, height, etc. of vehicle passengers as well as all the vehicle variables such as seat strength, rear end crushability, car body stiffness, relative size and speed of the two impacting vehicles, passenger compartment shape and size, and so on.

Nevertheless, the papers treated the subject in depth. Following are some facts and opinions gleaned from the references which were helpful in assessing the problem:

1. Accident study figures vary but rear-end accidents make up roughly 20-30% of all vehicle accidents. In California, nearly 20% of all freeway fatal accidents are rear-end accidents. This rate is high enough to cause concern about the effects of <u>all</u> rear-end accidents.

2. Injury rates also vary depending on the study, but it appears that 20-30% of rear-end accidents result in injury. A large percentage of these injuries are neck injuries (whiplash). Furthermore, many of these studies are based on police reports which only contain injuries reported within 24 hours of the accident. Since whiplash injuries often develop later, the reported injury rates may be low. This large incidence of whiplash-type injuries is also cause for concern.

3. Whiplash is a nonspecific, nonmedical term that refers, in general, to the severe backward movement and/or rotation of the head and neck. In rear-end accidents, even at relatively low speeds, the head may rotate back more than 90° with respect to the torso. Some of the symptoms of whiplash-type injuries include dizziness, hearing loss, visual disturbances including focusing difficulties, eye pain, and a number of other visual defects, abnormal EEG's, concussion, muscle tearing, hemorrhages of the esophagus, brain, thyroid gland and neck, separation of the intervertebral disc from adjacent vertebra, pain in the neck, head and shoulders, etc. Some of these symptoms are slow to disappear. Whiplash injuries are rare in head-on and side-impact accidents, probably because the head is blocked from excessive movement by the chest and shoulders respectively. However, there is no body "block" to limit the hyperextension (backward rotation) of the head and neck in rear-end accidents. Hence, the head restraint is necessary to counteract that type of head movement.

4. Researchers at UCLA concluded from full scale crash tests that seat backs should be 28 inches high minimum.

5. The distance or offset of the head from a seat back or head restraint does not appear to be critical, but it is preferable to have the head as close as possible to the restraints at the moment of impact.

6. Federal Motor Vehicle Safety Standard 202 made head restraints mandatory equipment for passenger cars sold in the United States after December 31, 1968.

7. Surveys show that head restraints, most of which were adjustable initially, were in the down position in up to 70% of cars which decreased their effectiveness, particularly for tall people. (The California Highway Patrol installs screw clamps on the head restraints in newly purchased patrol cars to keep the restraints in the up position.)

8. Seat and head restraint stiffnesses should be similar so that the torso and head move back and spring forward at the same rate during rear-end accidents. It appears that a well-padded, nonyielding seat back and head rest may be the preferable design. Controlled yielding of the seat framework is difficult to design properly for a range of impact conditions; it may allow a passenger who rotates back with the seat to raise up and allow the head to hyperextend over the seat back or head restraint; it may impinge on rear seat passengers, etc. Some head and chest injuries have been reported due to rear passenger contact with head restraints during <u>head-on</u> impacts.

9. Human volunteers subjected to rearward acceleration in sled tests experienced neck and back pain lasting several days after decelerations of -9.6 G's but not after -6.8 G's. Duration of the acceleration pulse at these G levels was not given.

10. Other studies gave head and neck tolerances in terms of moments and forces which could not be measured in the Caltrans crash tests. Some researchers concluded neck extension should be limited to 60-80° to avoid injury.

11. The tests by UCLA involved two identical sized Ford cars. There was considerable sheet metal crush in the rear ends which "softened" the impact for passengers in the front car. One of the papers describes an impact in

which the front vehicle had a rigid trailer hitch attached at the rear. This increased the accelerations felt by the passengers. Similarly, a truck with a rigid frame and body would transmit a larger force to the truck driver than if the rear end of the truck was crushable sheet metal.

12. Dummies do not appear to provide a very accurate way of simulating human necks, although the general motions of the dummy have been useful in evaluating full scale test results.

13. In the City of Rochester study, it was concluded that head restraints reduced the frequency of whiplash by 14%. The researchers conclude that this figure could have been much higher had users adjusted their head restraints properly and had the restraints been better designed.

14. Head restraints, properly designed and positioned, appear to be very effective in preventing whiplash injuries in relatively high speed impacts.

15. Some testing has been done on deployable head restraints. Inflatable bag type restraints looked the most promising.

Reference 11 has a list of 92 references and does an excellent job of summarizing all that literature in addition to reporting results of the author's own study on the effectiveness of head restraints.

Reference 5 describes in considerable detail a series of rear end impacts of passenger cars traveling 55 mph conducted at UCLA. Dummies were placed in all seating positions, various seat and head restraint designs were studied, and extensive data was obtained. Reference 15 is the Federal Motor Vehicle Safety Standard for testing head restraints required in passenger cars.

Reference List for Appendix F

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2. Mertz, H. J., Jr., and L. M. Patrick, "Investigation of the Kinematics and Kinetics of Whiplash," 11th Stapp Car Crash Conference Proceedings, Society of Automotive Engineers, Inc., October 10-11, 1967.

3. Severy, Derwyn M., Harrison M. Brink and Jack D. Baird, "Preliminary Findings of Head Support Designs," 11th Stapp Car Crash Conference, Society of Automotive Engineers, Inc, October 10-11, 1967.

4. Martinez, John L., "Headrest and Seat Back Design Proposals," Proceedings of Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., October 22-23, 1968.

5. Severy, Derwyn M., Harrison M. Brink, and Jack D. Baird, "Vehicle Design for Passenger Protection from High-Speed Rear-End Collisions," Proceedings of Twelfth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., October 22-23, 1968.

6. Severy, Derwyn M., Harrison M. Brink, Jack D. Baird, and David M. Blaisdell, "Safer Seat Designs," Proceedings of Thirteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., December 2-4, 1969.

7. Portnoy, Harold D., et al, "Intracranial Pressure and Head Acceleration During Whiplash," Proceedings of Fourteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., November 17-18, 1970.

8. Melvin, J. W., J. H. McElhaney, V. L. Roberts, and H. D. Portnoy, "Deployable Head Restraints - A feasibility Study," Proceedings of Fifteenth Stapp Car Crash Conference, Society of Automotive Engineers, Inc., November 17-19, 1971.

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